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FINAL REPORT ABOVEGROUND STORAGE TANKS (AST) LEAK DETECTION AND MONITORING

by
Naval Facilities Engineering Service Center
Vista Engineering Technologies, L.L.C.

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14. ABSTRACT

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Engineering Technologies, L.L.C., and Vista Research, Inc., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for aboveground storage tanks (AST). The *Low-Range Differential Pressure (LRDP)* system is a computer-controlled system that can reliably detect small leaks in ASTs, which range in size from 50,000 gal to ASTs with diameters of over 260 ft and containing over 10,000,000 gal of petroleum fuel. While no specific national regulatory requirements presently exist for ASTs, stringent state requirements are forcing Department of Defense (DoD) facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. With a validated, high-performance, in-tank leak-detection system for ASTs, like the LRDP, an alternative strategy is now available that is cost effective and does not necessitate taking the tank out of service. The results of the evaluation showed that the LRDP has the performance to meet the monthly monitoring and annual precision (tightness) test regulatory compliance requirements set for bulk underground storage tanks (UST) using a test that takes less than 24 h to conduct.

This project was performed under the *Environmental Security Technology Certification Program (ESTCP)*. The objective of the ESTCP is to demonstrate and validate innovative environmental technologies that are needed to address the environmental objectives of the DoD, that are cost effective, and that will be ready for the development of commercial products and services at the completion of the DEM/VALs. All of the objectives of the project have been met, and the LRDP is ready for and is currently in commercial use.

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ESTCP
Final Report

Aboveground Storage Tank (AST) Leak Detection and Monitoring

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Abstract

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Engineering Technologies, L.L.C., and Vista Research, Inc., have demonstrated and validated (DEM/VAL) an innovative mass-based leak detection system for aboveground storage tanks (ASTs). The *Low-Range Differential Pressure (LRDP)* system is a computer-controlled system that can reliably detect small leaks in ASTs, which range in size from 50,000 gal to ASTs with diameters of over 260 ft and containing over 10,000,000 gal of petroleum fuel. While no specific national regulatory requirements presently exist for ASTs, stringent state requirements are forcing Department of Defense (DoD) facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. With a validated, high-performance, in-tank leak-detection system for ASTs, like the LRDP, an alternative strategy is now available that is cost effective and does not necessitate taking the tank out of service. The results of the evaluation showed that the LRDP has the performance to meet the monthly monitoring and annual precision (tightness) test regulatory compliance requirements set for bulk underground storage tanks (USTs) using a test that takes less than 24 h to conduct.

This project was performed under the *Environmental Security Technology Certification Program (ESTCP)*. The objective of the ESTCP is to demonstrate and validate innovative environmental technologies that are needed to address the environmental objectives of the DoD, that are cost effective, and that will be ready for the development of commercial products and services at the completion of the DEM/VALs. All of the objectives of the project have been met, and the LRDP is ready for and is currently in commercial use. Both (1) on-line, permanently installed monitoring and testing systems and (2) tightness testing services using the LRDP can be obtained commercially through Vista Research. The results are described in the ESTCP final report and a published paper [1,2].

In a previous ESTCP project, the LRDP was demonstrated and validated for bulk USTs in a 122.5-ft-diameter bulk UST containing 2,100,000 gal of fuel at the Point Loma Fuel Terminal, San Diego, California. The LRDP used in this AST evaluation is identical to the one used in these previous bulk UST DEM/VALs, except a temperature sensor was added to the outside wall of the tank and the test protocol was changed to require that the test begin and end at night.

The LRDP system is fully automatic and is comprised of (1) an innovative in-tank level sensing unit to measure temperature-compensated level changes in the tank, (2) a temperature sensor mounted on the external wall of the tank to compensate for the thermal expansion and contract of the wall during a test, (3) a remote test controller to collect and analyze the data from a test, and (4) a host computer to initiate, report, and archive the results of a test. The electronics meet Class 1, Div. 1 standards. The in-tank sensor can be installed through a standard 8-in.-diameter opening without removing fuel from the tank. and is comprised of (1) a vertical reference tube that spans the full usable height of the tank, (2) a sealed, bottom-mounted container that houses all of the level-measurement sensors, and (3) a special bellows-mounting system that is used to attach the system to the top of the tank. A valve at the bottom of the reference tube allows fuel from the tank to enter or leave the tube. When the tank is to be tested for leaks, the valve is automatically and electronically closed, thus isolating the fuel in the reference tube from that in

the tank. As the level of liquid in the tank fluctuates, the level of liquid in the closed reference tube mimics it—except when the change in level is due to a leak. A test can be initiated by an operator or can be automatically scheduled for a future date and time. In very large ASTs, like the one used in the third-party evaluation performed as part of this ESTCP program, the bottom 1 to 3 ft of the reference tube is shaped to match the cross-section changes produced by the sloping tank floor. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test all of the tanks in a fuel farm or a bulk storage facility.

Two AST DEM/VAL tests were conducted between September 2001 and September 2002 [3]. The objective of the first DEM/VAL was to demonstrate that the LRDP can be used to test fixed-roof ASTs with floating pans. This DEM/VAL was conducted in a 54-ft-diameter, fixed-roof tank with a floating pan at Fairchild Air Force Base between September 2001and February 2002. The results of this DEM/VAL showed that the LRDP could be used to perform accurate tests in a tank with a floating pan.

The objective of the second DEM/VAL was to determine the performance of the LRDP in an AST through a third-party evaluation following an evaluation procedure developed by the third-party evaluator that was similar to and compliant with EPA's standard test procedure for bulk USTs. The results of the evaluation are reported in terms of leak rate, probability of detection (P_D), and probability of false alarm (P_{FA}). The third-party evaluation was performed by Ken Wilcox Associates, Inc. (KWA), a nationally recognized third-party evaluator. The evaluation consisted of 24 blind tests conducted on a 164.5-ft-diameter, 6,470,000-gal bulk AST containing jet fuel (JP-8) and located at the Fleet Industrial Service Center (FISC), Pearl Harbor, Hawaii. The tests were conducted over a wide range of ambient air temperature and induced leak conditions beginning on June 19, 2002 and ending on August 29, 2002. Leaks were induced in 11 of the tests.

The results of the third-party evaluation, which are presented in this report, indicate that in a single 20-h test the LRDP-24 can detect a leak of 0.932 gal/h with a P_D of 95% and a P_{FA} of 5% in a 164.5-ft diameter tank. The performance of the LRDP-24 scales with the product surface area of the tank (i.e., the tank diameter squared) and improves as the tank diameter decreases. The third-party evaluation results indicate that the LRDP-24 can detect leaks as small as 0.2 gal/h in a single test in a 76-ft-diameter tank with a P_D = 95% and a $P_{FA} \leq$ 5%. By conducting and averaging four tests, a 0.2-gal/h leak can be detected in a 108-ft-diameter tank with the same probabilities of detection and false alarm. For monthly monitoring purposes, the LRDP-24 can detect leaks as small as 1.0 gal/h in a single test in a 170-ft-diameter tank with a P_D = 95% and a $P_{FA} \leq$ 5%. In addition to a P_{FA} = 5%, the LRDP can also be operated with P_{FA}s of 1%, 0.0016%, and << 0.001%.

The LRDP can realize significant cost savings in three areas. First, the LRDP allows the DoD a very much less expensive alternative for meeting various regulatory requirements that now require DoD facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. Second, the LRDP is significantly cheaper to purchase, operate, and maintain than other leak detection technologies because of the low recurring cost of each test performed. It is the only mass-based system that can be used as an on-line monitoring system that can perform both monthly monitoring tests and annual precision tests. Due to the precision test capability of the LRDP, for each tank brought into compliance, the LRDP can realize cost savings over other in-tank, mass-based ATG methods and other testing services using mass-based methods by a factor of 3:1 and 11:1, respectively, over a 10-year period. Due to the high recurring costs of in-tank tracer methods, the cost savings realized by the LRDP over these methods can be well over a factor of 5:1 over a 10-year period. The payback for a permanently install LRDP is less than a year when compared to using an in-tank testing service or a tracer method. Thus, savings of up to several tens of millions of dollars can be realized for each DoD fuel storage facility. Third, in addition to the installation and operational cost savings, the LRDP has the potential to save DoD many hundred of millions of dollars in terms of clean-up and tank replacement cost avoidance.

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Acronyms

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AST	Aboveground storage tank
CERF	Civil Engineering Research Foundation
CERL	Construction Engineering Research Laboratory (Army)
DESC	Defense Energy Support Center (DESC)
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EvTEC	Environmental Technology Evaluation Center
MDLR	Minimum Detectable Leak Rate
NAS	Naval Air Station
NFESC	Naval Facilities Engineering Service Center
NWGLDE	National Work Group on Leak Detection Evaluations
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
P_{MD}	Probability of Missed Detect
PLC	Programmable Logic Controller
PSA	Product surface area
RTD	Resistance Temperature Device
TLR	Target Leak Rate
UST	Underground Storage Tank
VR	Volume Rate

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The development of this technology was made possible through the Navy's Pollution Abatement Ashore Program managed by the Naval Facilities Engineering Command and sponsored by the Environmental Protection, Safety and Occupational Health Division (N45) of the Chief of Naval Operations, the Preproduction Initiative Program, and DoD's Environmental Security Technology Certification Program. The LRDP was initially developed by NFESC and Vista Research, Inc. This work was performed by Vista Engineering Technologies, L.L.C., the Naval Facilities Engineering Service Center (NFESC), and Vista Research, Inc.

The work on this ESTCP project was performed by Vista Engineering Technologies, L.L.C., the Naval Facilities Engineering Service Center (NFESC), and Vista Research, Inc. The persons performing the work are presented below.

Project Manager:	Leslie A. Karr, REM NFESC
Project Engineer:	William R. Major NFESC
Technical Director:	Dr. Joseph W. Maresca, Jr. Vista Engineering Technologies, L.L.C.
Design/Field Engineers:	William R. Pickett Vista Engineering Technologies, L.L.C.
	James W. Starr, P.E. Vista Research, Inc.

1.0 Introduction

1.1 Background

DoD owns more than 4,000 aboveground storage tanks (ASTs) of varying capacities. These ASTs range in size from 25-ft to over 165 ft in diameter and may contain up to 6.5 million gallons of fuel. A large number of ASTs have diameters of 40 to 80 ft. Although Federal regulations have deferred bulk ASTs from monthly monitoring and/or annual precision testing [1], stringent state requirements are forcing DoD facilities to take their tanks out of service to install double bottoms and perform interstitial monitoring. With a validated leak detection system for ASTs, an alternative strategy would become available that is cost effective and does not necessitate taking the tank out of service. A double-bottom regulatory approach presents a cost prohibitive problem for the DoD. The alternative, a leak-detection strategy, is attractive, but no online system currently exists that meets both monthly monitoring and annual precision testing requirements for these tanks. To address this situation, the Navy was funded to adapt and conduct a demonstration/validation (DEM/VAL) test of the *Low Range Differential Pressure (LRDP)* leak-detection system, which was originally developed for bulk underground storage tanks (USTs), for use on bulk ASTs [2-4].

The LRDP system is an innovative technology that will reliably and accurately detect small fuel leaks in the *bulk* underground storage tanks (USTs) that are owned or operated by the Department of Defense [5-11]. If a tank is leaking, the LRDP quantitatively measures the leak rate in gallons per hour, the quantity of regulatory interest. The LRDP for bulk USTs was demonstrated and validated in an ESTCP project completed in 2001 [8, 9]. Under the ESTCP project described herein, the LRDP was adapted for testing ASTs. Only two small but very important modifications were made. First, a temperature sensor was attached to the outside wall of the tank to compute the level changes associated with the thermal expansion and contraction of the wall. Second, the test was begun and ended at night (during darkness) so that the spatial variation in temperature due to direct solar heating and cooling on different parts of the tank could be minimized. Otherwise, the LRDP used in this AST evaluation is identical to the one used in the previous bulk UST evaluations.

The LRDP system can be used to test tanks ranging in capacity from 50,000 gallons to over 10 million gallons and will work for tanks with vertical walls and cone-shaped bottoms. The LRDP is a fully automatic, mass-based system, which is easy to install and use. It can be installed through a standard 8-in.-diameter opening without removing any fuel from the tank. The LRDP system can be permanently installed in a tank and used for on-line monitoring and precision (tightness) testing. It can also be used as a portable system for periodic testing of any tank in the fuel farm. The minimum duration of a test is 20 h.

The main source of error in testing ASTs for leaks, which was emphasized during the third-party evaluation, is produced by air temperature. The ambient diurnal temperature changes, which affect the thermal expansion and contraction of the fuel, the wall, and the instrumentation, may be 10 to 20^{o}F per day (0.42 to 0.83 ^{o}F/h), or more, for ASTs. In bulk USTs, ambient air temperature changes are not an important source of noise. The main source of noise is the temperature changes of the fuel, which are produced because there is an initial difference between the temperature of the fuel when transferred into the tank and the surrounding ground. In bulk USTs, the fuel temperature changes may range from 0.2 to 2.0°F per day (0.008 to 0.08°F/h) and are generally at the lower end of the range. The LRDP compensates for over 95% of all three of these thermally induced sources of error.

The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California, and its industrial partners, Vista Engineering Technologies, L.L.C., and Vista Research, Inc., has developed, evaluated and implemented the LRDP leak-detection system for bulk USTs. The LRDP has been evaluated for performance by a third party following an EPA standard test procedure for bulk USTs [12, 13] in three separate third-party evaluations [14-31]. The results of these evaluations have demonstrated that the LRDP has the performance to meet the very strict regulatory compliance standards for bulk USTs that were established for the highly regulated small USTs found at retail service stations [1] and at bulk UST facilities [32]. Furthermore, the LRDP is the only on-line system that can meet both the monthly monitoring and annual tightness test regulatory requirements [32].

1.2 Objectives of the Demonstration

The objective of this ESTCP project was to demonstrate and validate (DEM/VAL) a reliable, cost-effective leak-detection system for monthly monitoring and periodic precision testing of the *bulk* aboveground storage tanks (ASTs) that are owned and operated by the DoD. This project was an expansion of the previous ESTCP project conducted for bulk USTs [8, 9] by NFESC and its industrial partners.

Two AST DEM/VAL tests were conducted between September 2001 and September 2002. The objective of the first DEM/VAL was to determine the best way to test fixed-roof ASTs with floating pans and to conduct a leak detection test with the LRDP in this type of AST. The objective of the second DEM/VAL was to determine the performance of the LRDP in an AST through a third-party evaluation following EPA's standard test procedure for bulk USTs. The first DEM/VAL was conducted on a 54-ft-diameter, fixed-roof AST (with a floating pan) located at Fairchild AFB, and the second on a 164.5 ft-diameter fixed-roof AST at Pearl Harbor, Hawaii.

The output of the project is a pre-production prototype of the LRDP leak detection system (1) that is ready for use by industry and (2) that has been evaluated for performance by an independent third party following a *standard test procedure* developed by the EPA and ASTM [13, 33].

The performance objectives of the DEM/VALs were established by the regulatory guidelines developed in California for detection of leaks in *bulk* USTs [32]. The bulk UST regulatory guidelines were used, because quantitative standards for ASTs have yet to be developed, but any standards developed for ASTs will be no more stringent than those for bulk USTs.

The results of this evaluation are reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLRs for bulk USTs are typically 0.3 to 1.0 for monthly monitoring when a precision test at 0.2 gal/h is performed annually and 1.0 to 2.0 gal/h for monthly monitoring when the precision test is performed semi-annually [32].

1.3 Regulatory Drivers

In 1988, the U. S. Environmental Protection Agency (EPA) issued regulations that required periodic leak testing of underground storage tanks and their associated piping containing hazardous substances such a petroleum fuels. Only the shop-constructed USTs, which are typically used at service stations and have capacities of 50,000 gal or less, were strongly regulated. The UST regulation *deferred* the requirements for testing ASTs and field-erected (i.e., bulk) USTs for leaks [1], mainly because there were no viable technologies available in 1988 that could perform the tests and meet the performance standards established for the shop-constructed USTs. This deferral was also applied to airport, airfield, and marine hydrant fuel distribution pipeline systems. As a consequence, none of these large storage and distribution systems were required to meet the rigorous leak-detection performance standards for monthly monitoring or annual tightness testing established for the smaller USTs typically found at retail petroleum service stations [1]. While an aboveground tank is defined as any tank with less than 10% of the volume of the fuel contained underground, the bottom or buried surface area of an AST with a diameter of 31.3 ft, a very small AST, has the same buried surface area as a 10,000-gal UST, one of the larger shop-constructed USTs found at many retail service stations.

At the present time, ASTs are not strongly regulated and federal regulatory standards have not been established. It is clear from public and private forums, however, that many states are developing or have recently developed such regulations or regulatory guidelines. SPCC plans and API 653 inspections encourage leak detection but stop short of requiring it [34, 35]. However, SPCC encourages leak detection testing by allowing an increased interval between inspections. Also, leak detection has been found to be useful in verifying that a tank is leak free before it is brought back into service after an API 653 inspection.

The original reason for the deferrals from leak detection for the large bulk storage and transfer systems has been addressed. Technology now exists that can test these storage and transfer systems. Also, the owners and operators of field-erected, bulk USTs and hydrant systems are now highly regulated; strong regulations for owners and operators of ASTs will soon follow. Even more importantly, there is an operational driver for implementing leak detection in ASTs. In most states, the regulatory environment requires ASTs to have double-bottoms with leak detection in the interstitial space between the false existing and second bottom. As an alternative, these states will accept single-bottom tanks if reliable leak detection is permanently installed on the tank for routine monitoring and periodic precision testing. This option is very real and very attractive, because there is a cost savings of as high as 30:1 over that of double bottoms. Moreover, a major oil company has recently issued internal requirements to test their single-bottom ASTs every two years. This is a significant change of direction for the petroleum industry. Regulatory agencies are apt to require annual or more frequent precision tests.

As a testing standard for this ESTCP project, we used the bulk UST regulatory guidelines issued in California several years ago [32] and followed in the previous ESTCP project when evaluating the performance of the LRDP for bulk USTs [8, 9]. In California, the owners or operators of bulk

USTs must test monthly with a system that is capable of detecting a leak of either 1.0 or 2.0 gal/h and must test semi-annually or annually, respectively, with a system that can detect leaks of 0.2 gal/h; all systems used for monitoring and testing must have a P_D = 95% and a $P_{FA} \leq$ 5%. If the ASTs are periodically tested, the current and expensive practice (e.g., Florida) of taking the tank out of service and installing a double bottom with leak detection can be avoided.

1.4 Stakeholder/End-User Issues

The two DEM/VALs conducted as part of this ESTCP project demonstrate that a technology exists that can reliably, accurately, and cost effectively detect small leaks in ASTs. The system has the performance to test all of the ASTs owned and operated by DoD. In addition, the performance has been determined in a third-party evaluation, a prerequisite for purchase and use of the technology. The system can be permanently installed in a tank for monthly monitoring and precision testing, or it can be used as a portable system and moved from tank to tank or facility to facility to conduct a test.

The LRDP is ready for commercialization. Vista Research, Inc., has commercialized the LRDP and is now offering products and services based on the LRDP implemented using a PLC. Some limited sales of the LRDP have already occurred. For example, the LRDP has been used to test an AST at Point Loma and a chemical tank (containing sodium hydroxide) at an industrial facility.

2.0 Technology Description

The LRDP was originally developed for the reliable detection of small fuel leaks in the bulk USTs that are owned or operated by the Department of Defense [5-11]. The output of a leak detection test is a temperature-compensated volume rate (TCVR) in gallons per hour. If a tank is leaking, the output of the LRDP is the leak rate. The LRDP is a fully automatic, mass-based system, which is easy to install and use. The LRDP system can be permanently installed in a tank and used for on-line monitoring and precision (tightness) testing. It can also be used as a portable system for periodic testing of any tank in the fuel farm. The LRDP for bulk USTs can be used to conduct a test in 10, 24, or 48 h, depending on the type of test, performance required, and the time available to complete the test. The LRDP for bulk USTs was demonstrated and validated in an ESTCP project completed in 2001, and a thorough description of the technology is presented in the final report [9].

Under this ESTCP project, the LRDP was adapted for testing ASTs. Only two small but very important modifications were made. First, a temperature sensor was attached to the outside wall of the tank to compute the level changes associated with the thermal expansion and contraction of the wall. Second, the test was begun and ended at night (during darkness) so that the spatial variation in temperature due to direct solar heating and cooling on different parts of the tank could be minimized. Otherwise, the LRDP used in this AST evaluation is identical to the one used in the previous bulk UST evaluations.

A description of the LRDP technology for bulk ASTs is presented below. To avoid redundancy, the reader is referred to the ESTCP reports of the LRDP for bulk USTs for additional details [8, 9].

2.1 Technology Development and Application

The LRDP system is fully automatic and is comprised of (1) an innovative in-tank level sensing unit, (2) a temperature sensor mounted to the outside wall of the AST, (3) a programmable logic controller (PLC) or an embedded remote test controller to collect and analyze the data from a test, and (4) a host computer to initiate, report, and archive the results of a test. The in-tank sensor is comprised of a reference tube, which extends from the bottom of the tank to above the highest anticipated fuel level, a sealed container at the bottom of the reference tube, which houses the measurement sensors, and a valve at the bottom of the tube to allow fuel in the tank to enter the tube.

2.1.1 Description

The pre-production prototype of the LRDP system for use in ASTs is shown in Figure 1. In Figure 1, the LRDP is shown being installed in the fixed-roof AST with a floating pan that was used in the first DEM/VAL. The level-measurement sensor is an off-the-shelf, industrial-grade differential pressure (DP) sensor that is located in a sealed container at the bottom of the in-tank sensing unit. Level measurements are made with a precision of 0.0002 in. Figure 1 also shows the tripod used to install the in-tank level sensing unit through an 8-in.-diameter opening at the top of the tank. A test is initiated by an operator using the host computer. The PLC (i.e., remote test controller), located in close proximity to the tank, automatically operates the LRDP system. A test report is generated upon completion of the test. The LRDP system is compatible with the DoD Fuels Accounting System (FAS) and can be integrated with FAS to test the tanks in a fuel farm or bulk storage terminal.

The results of a test are Pass, Fail, or Inconclusive. A volume rate (i.e., a leak rate) is reported only if the tank fails the test. An inconclusive test occurs if the data fail a data quality test, and it is recommended that the test be repeated. A number of data quality indices ("DQIs") have been developed for the LRDP. These DQIs, based on empirical data, assure the data used to compute the test result are of sufficient quality for analysis. Data quality tests are performed to determine whether or not (1) a pump was inadvertently turned on during a test, (2) a sample of fuel was obtained during a test, (2) a valve isolating the tank was prematurely opened before the test was completed, (4) data sampling problem was experienced such as a data drop-out or a wild point, (5) an unexpectedly high level of noise occurred due to excessive wind or an extreme weather event, or (6) the trend of the temperature compensated level data changed significantly during the test. A test is judged to be inconclusive if any one of the data quality indices (DQIs) developed to test for each problem exceeds a defined threshold, and it is recommended that the test be repeated.

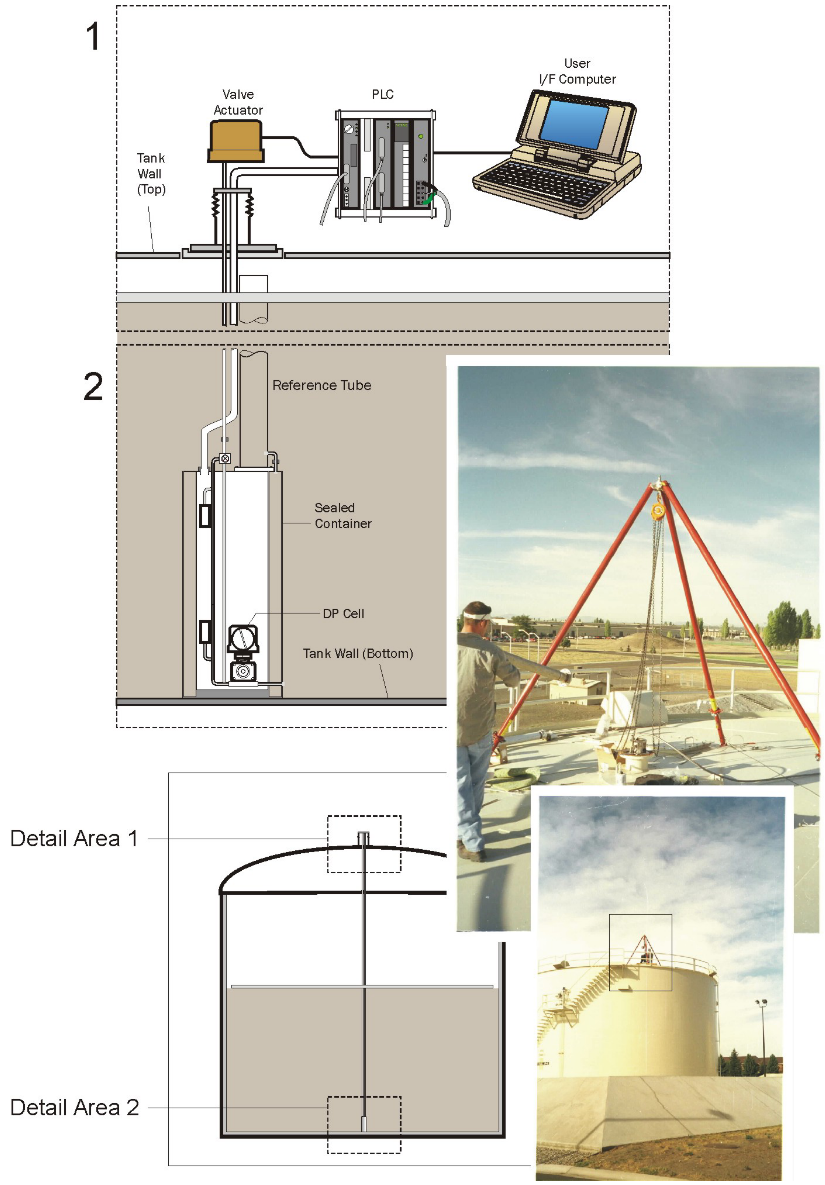

Figure 1. Low-Range Differential Pressure (LRDP) system for ASTs.

During the evaluation, the data quality indices were set sufficiently high so that all of the data would be of sufficient quality to use except for very extreme problems. This was required to minimize the time required to complete the evaluation. It was justified because many of the problems that might be encountered operationally would not be encountered during a controlled evaluation (e.g., a transfer during the middle of a test).

High performance is achieved with the LRDP system, because the novel design of the in-tank sensing unit results in (1) a very high precision for making level measurements with an off-the-shelf differential pressure (DP) sensor and (2) effective compensation of the thermally induced level changes produced by temperature changes of the fuel, the sensors, the tank, and the mounting system. Accurate compensation is obtained because the LRDP is specifically designed to compensate for each source of noise without the need for arrays of temperature sensors or delicate and expensive level sensors. As a consequence, all of the sensors are off-the-shelf, commercially available sensors that have a proven track record of performance. The reference tube, a special bellows-mounting stand at the top of the tank, bottom-mounted sensors, and externally mounted temperature sensor are the key elements that lead to high performance. Other mass-based systems do not work as well, because (1) the sensors are mounted at the top of the tank where the top of the tank moves vertically in response to large diurnal swings in the ambient air temperature, (2) the thermal expansion and contraction of the shell is not accurately compensated, (3) the pressure sensor is very delicate and expensive to achieve the level of precision required to conduct a test, and (4) the pressure sensor may require the use of nitrogen gas for operation.

The LRDP is the only in-tank system that has the performance to address both the monthly monitoring and annual precision test leak-detection regulatory requirements for bulk USTs [5-11] without requiring the installation, operation and cost of a second system. This is also true for use of the LRDP for ASTs [2, 3]. Not only is the LRDP the only system that can cost effectively meet both requirements, it can meet these requirements with a very low probability of false alarm.

The *in-tank level sensing unit* of the LRDP system that has been designed for bulk ASTs is comprised of the following:

(1) a **reference tube** that extends from the top to the bottom of the tank

(2) a **valve**, located near the bottom of the tank, with which to open and close the tube

(3) a **sealed container** mounted at the bottom of the reference tube and containing all of the level-measurement sensors

(4) a **differential pressure sensor**, mounted in the sealed container, that measures the *difference* between the level of liquid in the tank and that in the reference tube

(5) a **pressure sensor**, mounted in the sealed container, that can be used to measure the level of the fuel in the tank

(6) a second **pressure sensor**, mounted in the sealed container, that can be used to measure the specific gravity of the fuel in the tank

(7) a **temperature sensor**, mounted on the differential pressure cell in the sealed container, that can be used to compensate the differential pressure sensor or the pressure sensors for temperature, and/or to measure the temperature of the fuel at the bottom of the tank

(8) a **temperature sensor**, mounted on the external shell (tank wall) of the tank, that can be used to compensate the volume (level) changes produced by the thermal expansion or contraction of the wall during a test.

(9) **electrical wires** (4-20 ma contained in a sealed conduit) that connect the bottom-

mounted sensors to the data acquisition system outside the tank, and

(10) a special bellows-mechanical **mounting** system to eliminate thermal movement of the reference tube and transducer enclosure attached to the top of the tank.

The fuel in the tank is allowed to enter or leave the reference tube through a valve located at the bottom of the tube. The valve is opened and closed electronically (a function that can also be done manually). Except for a test, the valve is left in the open position. This allows fuel from the tank to enter the reference tube until the level of liquid is the same in both. When the valve is open, i.e., when the level of liquid in the tube is identical to that in the tank, the precision and accuracy of the LRDP system can be checked, because only the random fluctuations in the level are observed; with the valve open, there can be no changes in the mean level over time. When the tank is to be tested, the valve is closed, isolating the fuel in the tube from the fuel in the rest of the tank. With the exception of a level change due to a leak and the thermal expansion or contract of the tank wall, the level of the fuel in the reference tube mimics the level of the fuel in the tank.

The DP sensor measures the difference in the levels of fuel between the reference tube and the tank (which can be expressed in terms of gallons per hour based on a height-to-volume conversion (HVC) from the tank's strapping table). The volume change is then compensated for the thermal expansion and contraction of the tank wall. The output of a test is a temperature-compensated volume rate (TCVR). If the TCVR exceeds a pre-set detection threshold, the tank fails the test.

For high performance, a test should begin and end at night, and it should be long enough to average through a diurnal cycle. The TCVR is obtained by using two 30-min periods of data at the start and end of the test. It was intended that the test duration would be 24 h. However, to minimize the time required to conduct the third-party evaluation, the test was shortened to 20 h. This allowed a test to begin and end during the night and still leave sufficient time to prepare different leak conditions during the evaluation.

The *PLC*, shown in Figure 1, is used to control the temperature sensors, the differential pressure sensor, and the valve motor. An embedded controlled was used to control and collect the data in previously implementations of the LRDP. As configured for the evaluation, the PLC collected 8 channels of data, but more channels can be added, if required. For this evaluation, three RTD temperature sensors were mounted on the north, southeast and southwest wall of the AST. An RTD temperature sensor was also mounted on the DP sensor and in the PLC.

The *host computer* is used to initiate a test, inspect the results in real-time, and report and store the results of a test. The graphical user interface is easy to use. A test is initiated by pressing a Start Test button. The analysis not only includes a computation of the measured volume rate, which is equal to the leak rate, if a leak is present, but also includes a comprehensive set of quantitative data quality indices (DQIs) that automatically assess the quality of the data before the data are used to complete a test.

2.1.2 Software

In the previous ESTCP report, a description of the embedded controller and its software was described [9]. In these DEM/VALs, the LRDP was implemented using a PLC. Appendix A illustrates typical input/output displays. Figure A-1 allows the operator to enter information that describes the test being performed. Figure A-2 is the user display that allows a test to be started or stop and to see real-time updates of what each sensor is measuring. A test can be initiated by clicking on a start button. The other two displays, Figures A-3 and A-4, are set up during the installation of the LRDP and do not generally need to be changed.

2.1.3 Testing Algorithm

The output of a leak detection test is a temperature compensated volume rate (TCVR). It is obtained by collecting and averaging 15, 30 or 60 min of level data from the DP sensor at the beginning and end of a test. These data are obtained when the reference tube is closed. For these tests, a 30-min average was used.

The average level of fuel in the AST obtained at the beginning of the test is subtracted from the average level of fuel in the AST obtained at the end of the test and divided by the mean time between these two level measurements to obtain rate of level change. A volume rate (VR) is determined from this level rate by using the HVC obtained from the product surface area of the tank. The apparent walled-induced volume change of the fuel in the tank (TVR_{wall}) is determined from the changes in the level of fuel in the tank due to thermal expansion and contraction of the tank walls is computed using the average temperature measured with the temperature sensor on the North side of the tank during the same two 30-min time periods.

The average of a 30-min segment of data obtained by the DP sensor and the AST wall temperature sensor data were used to compute the change in the LRDP volume and the Wall Volume over a 20-h period. For the evaluation, the test started at 0530 and ended at 0200. Thus, the 30-min periods were from 0530 to 0600 and from 0130 to 0200. Any set of start or end times after 2200 and before sunrise (~0630) that resulted in a 20-h test or longer would have sufficed.

The output of a leak detection test, the temperature compensated volume rate (TCVR), was computed over this 20-h period as follows:

$$TCVR = VR - TVR_{wall} = [HVC\ (<LRDP_{End}> - <LRDP_{Start}>) - (<\text{Wall Volume}_{End}> - <\text{Wall Volume}_{Start}>)]/20,$$

where, average is denoted by < >, the LRDP level measurements were made in inches of fuel and the Wall Volume changes are computed assuming that the change in the circumference of the AST due to thermal expansion and contract of the tank wall is a maximum at the fuel surface and does not change at the base of the tank.

While a test can begin or end at any point in the day or night, for best performance using only a single wall-mounted temperature sensor, the test should begin and end at night and be long enough to average through a diurnal cycle. It was intended that the test duration would be 24 h. However, to minimize the time required to conduct the third-party evaluation with a start time after midnight, the test was shortened to 20 h. This allowed a test to begin and end during the night and still leave sufficient time to prepare different leak conditions during the evaluation.

A number of data quality indices ("DQIs") have been developed for the LRDP. These DQIs, based on empirical data, assure the data used to compute the test result are of sufficient quality for analysis. As explained above, the DQIs verify that there were no product transfers, product sampling, data acquisition problems, or unusual weather conditions during the test.

Once the data are qualified and a test result, TCVR, is computed, there are a variety of detection thresholds, T, that might be used to determine whether or not the AST has a leak. The detection threshold is set to maintain a specified probability of false alarm (P_{FA}) and a probability of detection (P_D) of 95% against the target leak rate of regulatory or operational interest. The largest P_{FA} that can be used is 5%. If possible, a P_{FA} of 1%, or less, should be used. It is important to realize that once the threshold is selected, the P_{FA} is established. It is equally true that once the P_{FA} is specified, the threshold is also established. Changing one automatically changes the other. The detection threshold can be computed as a function of tank diameter (i.e., product surface area, PSA). The performance of the LRDP can be improved by averaging two or more tests together before applying the threshold, or by increasing the test duration. A test duration that extends through three night-time periods (two diurnal cycles) would give better performance than a test through only two night-time periods (one diurnal cycle).

2.1.4 Conduct of a Test

While a waiting period (the time between the last transfer into and out of the tank and the start of a test) is not needed, a short waiting period of 1 h or so is recommended after all of the valves are closed and the AST is ready for testing. This waiting period is not necessary from a performance stand point, but practically, it insures that the tank has been prepared for a test, i.e., all valves have been closed and any drainback or disturbance from pumps etc. have been minimized. The basic procedure for conducting a test is described below.

- Specify what type of test will be conducted (i.e., the test duration) and what waiting period will be used
- Specify the threshold to be used in determining whether or not the tank passes or fails the test
- The valve at the bottom of the reference tube is automatically left open between tests and the level of the fuel in the tube should be at the same level as the fuel in the tank
- If the LRDP is being inserted into the tank for a test, allow the reference tube to fill up with fuel so that the fuel in the tube and in the tank is at the same level
- Close the valve to isolate the fuel in the reference tube from the fuel in the tank
- Begin collecting data with the LRDP. The data collected during the waiting is not used in the analysis. The data collected following the waiting period is used in the analysis.
- Generate a time series of the difference in the level changes in the tube and the tank using the pressure measurements obtained with the DP sensor. Level measurements are obtained by dividing the pressure measurements by the specific gravity of the fuel (e.g., 0.82).

- Convert the level time series to a volume time series using the height-to-volume conversion (HVC) factor for the tank. For a 164.5-ft-diameter tank, the HVC factor is 13,248.6 gal/in.
- Apply a set of Data Quality Indices (DQIs) to the volume time series to determine if the data collected is of sufficient quality to be used in a test. If a data quality problem is encountered during the first half of a test, the test is automatically extended by a time interval equal to half the test duration. If a problem is encountered during the second half of the test, the test is automatically repeated. The test operator can abort the test at any time if there is not enough time to complete the tests before normal operations begin. Thus, the test may be extended either 12 or 24 h for a 24-h test, depending on which half of the test data is of poor quality. If the test is extended, at present, the software only allows an extension equal to the duration of the test. If the extended test data fail the DQI tests, then another test can be initiated immediately or at a later time.
- If the data fail the DQI tests, then the output of the test is *Inconclusive* and must be repeated.
- If the data pass the DQI tests, then the rate of change of volume is computed by fitting a regression line to the volume time series data
- The measured volume rate is compared to the detection threshold to determine whether the test is a *Pass* or a *Fail*. The tank passes the test if the measured volume rate is less than or equal to the threshold. If the tank fails the test, the tank and the test data should be checked for problems, and then the tank should be re-tested. A leak rate is only printed out if the tank fails the test.

2.1.5 Testing Methods

Table 1 summarizes two general methods for conducting a test with the LRDP system that are designed to address the regulatory requirements summarized in Section 2.2. The name of the method contains the duration of the test in hours and the number of tests to be averaged. In previous tests, a 24-h test was evaluated, and the method was designated as the LRDP-24. In this evaluation, a 20-h test was used. For historical consistency, the name of the method was kept as the LRDP-24, even though a slightly shorter test duration is possible.

Table 1. Summary of the Two Methods of the LRDP System for Bulk Tanks

Name of Test Method	Type of Test	Test Duration	Number of Tests Averaged Together
LRDP-24 Version 2	Monitoring, Precision*	20 h	1 test
LRDP-24-n Version 2	Precision*	20 h	1 < n ≤ 24 tests

* Can be used to address the regulatory standards for a 0.20-gal precision test.

For ASTs, the LRDP-24 can be implemented with a test duration of 20-h test, or longer. The LRDP-24-n is a test that requires the averaging of “n” LRDP-24 tests. As determined from the third-party evaluation, both methods can be used to test vertical-walled tanks with capacities greater than 50,000 gal and diameters less than 260 ft. The performance of the LRDP-24 scales linearly with the product surface area (PSA). The performance results for the LRDP-24-n scales inversely by the square root of the number of tests, n, averaged together, and linearly with the PSA. Both the LRDP-24 and the LRDP-24-n can be used as a stand-alone monitoring and precision testing system or a portable precision testing system (as part of a testing service). The

name of the method is designated as *Version 2* to differentiate the performance of the LRDP-24 for ASTs from the LRDP-24 for bulk USTs, which is designated as Version 1.
Both methods are performed using a test duration of 20-h test or more. The only difference between the LRDP-24 and the LRDP-24-n is that up to 24 tests may be averaged together before determining whether or not the tank is leaking. The number of tests to be averaged depends on the required performance. This type of method is normally used to meet the 0.2-gal/h precision (tightness) test requirement for the larger tanks owned by DoD, but may also be used to meet the monitoring requirements with a lower P_{FA}. No waiting period is required between the time of the last transfer and the beginning of a test as it would be for level and temperature measurement systems (i.e., volumetric systems).

For both methods in Table 1, one of five *detection thresholds* are presented that can be used to detect a specific target leak rate (TLR) with a $P_D = 95\%$, or to operate with a specific $P_{FA} \leq 5\%$. These thresholds were selected to insure that the LRDP system could be used as needed to satisfy specific regulatory TLRs, to operate the LRDP with P_{FA} less than 5%, and to compare the performance of the LRDP directly to other methods of leak detection. As a consequence, there are 10 different ways to use the LRDP for testing tanks, and the evaluation results are described in four pairs of KWA evaluation reports [36-41]. Actually, there are many more thresholds that can be used, but the National Work Group on Leak Detection Evaluations (NWGLDE) has only allowed four to be presented.

2.1.6 Operations

2.1.6.1 Mobilization

The LRDP system can be transported to a measurement site in its main component sections. The reference tube is comprised of two or more sections of flanged pipe, which can be assembled on site during installation. Installation and removal of the equipment for a leak detection test each takes about 1 day to complete. For more complicated installations, a two-day period might be required.

2.1.6.2 Test Set-up

The LRDP system can be installed for a test, when used as a portable system, in less than 4 hours. It takes between one and three days for a permanent installation of the in-tank sensing unit.

2.1.6.3 Training

A field technician with experience in operating computer-controlled equipment can learn to operate the system in less than a day. The physical set-up of the equipment and the methods for mounting the LRDP in the tank is straightforward. The system checkout and use of the software is also straightforward. The system is automatic and a test is initiated by clicking on the start button on the Graphical User Interface (GUI). If desired, text can be added to the header to more fully document the test. There are several user screens that are used to configure the system for operation. Once set, these screens do not generally need to be changed.

2.1.6.4 Quality Assurance

The DEM/VALs were conducted in accordance with the Quality Assurance Plan presented in the ESTCP Technology Demonstration Plan [4]. This plan is attached as Appendix B of this final report. The plan is consistent with the third party evaluation protocol [33].

2.1.6.5 Health and Safety

The LRDP system is safe to use and poses no health risk to the user or the AST. The system requires 110 VAC power, but can and was operated off of a generator when used as part of a testing service. The Health and Safety Plan followed during the two DEM/VALs is described in the ESTCP Technology Demonstration Plan [4] and is attached as Appendix C of this final report.

2.2 Previous Testing of the Technology

Over the past six years, the NFESC, in conjunction with its industrial partners, has developed, evaluated and implemented the LRDP leak-detection system for bulk USTs [5-11]. The LRDP has been evaluated for performance by a third party following an EPA standard test procedure for bulk USTs [12, 13] and bulk ASTs [33]. Three separate third-party evaluations have been performed in tanks of different sizes, locations, and climatic conditions. The evaluations were performed (1) in an 88-ft-diameter bulk UST containing 650,000 gal of fuel at the NAS North Island [5, 14-21], (2) in a 122.5-ft-diameter bulk UST containing 2,100,000 gal of fuel at the Point Loma Fuel Terminal[8-9, 22-30], and (3) in the world's largest tanks having a diameter of 100 ft and containing 12,500,000 gal of fuel [6, 10, 31]. The system has also been demonstrated on a 50,000-gal, shop-fabricated UST at the Hunter Army Air Field, Fort Stewart [8, 9]. The results of all three evaluations were similar and are consistent with the results of the LRDP obtained in this AST third-party evaluation [36-41]. The results of these evaluations have demonstrated that the LRDP, both as an on-line, permanently installed system and a portable system used as part of a testing service, has the performance to meet the very strict regulatory compliance standards in bulk USTs that were established for the highly regulated small USTs found at retail service stations and bulk USTs in California [1, 32].

2.3 Factors Influencing Cost and Performance

Unlike remediation technologies, the performance of an LRDP is essentially independent of the site and the facility, because through the third-party evaluation, the performance is estimated over a range of conditions that the system will operate. While these conditions may not include the extremes, they are sufficient to identify performance problems that might be encountered under more challenging conditions. The main factor influencing the performance of the LRDP system (and other mass-based systems) is the size of the tank. The performance of the LRDP scales with the product surface area (tank diameter squared) in a prescribed way as determined by the third-party evaluation [36-41].

The main sources of problems during a test are operational ones. It is important that the tank is completely isolated from the associated piping, i.e., all valves are completely sealed, before a test is initiated. It is also important that any drainback of fuel into the tank has ceased before a test is initiated.

The LRDP is designed to fit into a standard 8-in.-diameter opening in a tank. The initial purchase cost, the installation cost, and the cost of operational use and maintenance are not affected by site parameters or site geology. This assumes that electrical power is available at each tank and that communication cable has already been installed between each tank and the building where the host computer is located. This assumption is valid, because systems used to acquire inventory level data are currently being used at each site. The cost differential between an LRDP in a bulk AST with a small height (e.g., 20 ft) versus a large height (e.g., 40 ft) is insignificant and is attributed to the cost of a longer reference tube.

2.4 Advantages and Limitations of the Technology

There are seven other types of systems besides the LRDP that can be used to detect leaks in ASTs: (1) in-tank tracer systems, (2) testing service mass-based systems, (3) in-tank mass-based systems, (4) constituent fuel tracer systems, (5) in-tank level and temperature monitoring systems, (6) acoustic systems, and (7) statistical inventory reconciliation systems. The last four types of systems, (4) through (7), do not have the accuracy or reliability for use as either a monthly monitoring system or a precision test system for ASTs. The third type of system can meet the monthly monitoring requirements, but does not have the accuracy or reliability to perform a precision test. Only the first two systems can also be used to meet both the monthly monitoring and precision test requirement, but, as described in Section 5, the cost of test is significantly greater than that of the LRDP.

The LRDP system has the following advantages for testing ASTs:

- The LRDP can be directly inserted into a standard 8-in.-diameter opening in the tank.
- The LRDP can be installed and used without removing fuel from the tank.
- The LRDP can be used to test a bulk ASTs in as little as 20 h, which is a significantly shorter test duration than other methods (48 to 72 h or longer).
- The LRDP can be used to test ASTs (and USTs) with both vertical and curved walls.
- The output of a leak detection test is easy to interpret, because it is a direct measurement of the leak rate in gallons per hour, the quantity of regulatory and engineering interest.
- The LRDP system has been successfully demonstrated in a variety of different types of ASTs (fixed roof and floating pan tanks) and different size DoD tanks (including the largest ASTs owned by the DoD).
- The LRDP system for bulk USTs has been evaluated for performance by an independent third party in accordance with the standard test procedures required for a listing with the National Work Group on Leak Detection Evaluations, a nationally recognized, regulatory group.
- The LRDP system is the only mass-based system that can meet both the monthly monitoring and the semi-annual or annual precision test regulatory guidelines required in California for testing bulk USTs.

- Because the LRDP system is a mass-based system, it inherently compensates for the thermal expansion or contraction of the fuel in the tank during a test. Furthermore, accurate tests can be initiated without a long pre-test waiting period.
- The bellows-mounting system eliminates thermally induced movement of the reference tube during a test.
- Thermally induced drift of the differential pressure sensor is virtually eliminated, because it is mounted in a sealed container at the bottom of the tank.
- Level changes due to thermal expansion and contraction of the wall of an AST are compensated using a single temperature sensor mounted on the external wall of the tank.
- Because the differential pressure sensor used to measure level (volume) changes in the tank needs a dynamic range of only 0.5 in. (rather than the total height of the tank, like other mass-based systems), the LRDP has the precision (0.0002 in.) to detect very small leaks in large-diameter tanks.
- The system is self-calibrating, and the performance and functionality of the LRDP can easily be checked between leak detection tests when the reference tube is in direct communication with the fuel in the tank.
- The sensors used to measure differential pressure, pressure, and temperature are robust and have been used commercially in the pipeline leak detection systems that Vista Research has been selling for many years.
- The cost of a testing program, which includes monthly monitoring and precision testing, is a factor of 3 to 11 times less expensive using the LRDP system than using other in-tank, mass-based or tracer systems.
- There is less than a one-year payback for the LRDP when it is permanently installed as compared to monthly monitoring and annual precision tests conducted with a testing service and an in-tank tracer system.

The main limitation of the method is that all of the valves in the fuel facility that isolate the tank from its associated piping must seal completely; if these valves do not completely seal, the LRDP system will detect this flow. This is not usually a problem for monitoring, because the monitoring standards are high enough to accommodate small flows across the valve. For precision tests, however, the valves must seal completely. If the tank fails a test (either a monitoring or precision test), a detailed inspection of the tank and pipe valves is performed next assuming that this is the reason for the failed test, and if necessary, valve blinds are installed to complete the test. In many instances, simply closing the valves more tightly is all that is needed. The magnitude of this problem is not known for bulk ASTs, but it is the same problem encountered and successfully addressed for routine monitoring of underground storage tanks at service stations.

3.0 Demonstration Design

3.1 Performance Objectives

The objective of this ESTCP project was to demonstrate and validate (DEM/VAL) a reliable, cost-effective leak-detection system for monthly monitoring and periodic precision testing of the *bulk* aboveground storage tanks (ASTs) that are owned and operated by the DoD. This project was an expansion of the previous ESTCP project conducted for bulk USTs [9-11]. The DEM/VALs were designed to demonstrate the system on fixed-roof tanks with and without a floating pan and to have the performance documented in a third-party evaluation. The output of the project is a pre-production prototype of the LRDP leak detection system (1) that is ready for use by industry and (2) that has been evaluated for performance by an independent third party following a *standard test procedure* developed by the EPA and ASTM [13, 33].

The performance objectives of the DEM/VALs were established by the regulatory guidelines developed in California for detection of leaks in *bulk* USTs [32]. The bulk UST regulatory guidelines were used, because quantitative standards for ASTs have yet to be developed. Furthermore, these regulatory standards are practical and very stringent.

The results of this evaluation are reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLRs for bulk USTs are typically 0.3 to 1.0 for monthly monitoring when a precision test at 0.2 gal/h is performed annually and 1.0 to 2.0 gal/h for monthly monitoring when the precision test is performed semi-annually [32].

3.2 Selection of a Test Site/Facility

Since the LRDP leak-detection system is not affected by soil conditions and site geology, four criteria were used in selecting sites for the DEM/VALs. The primary criteria for a demonstration site are AST size, type of tank, tank integrity, and tank availability and base facility support. First, it was desired to perform the DEM/VAL in a tank with a large enough diameter to address all of the tanks used by DoD. The standard test procedure for bulk ASTs described in [33] allows the results of the evaluation for mass-based systems in a bulk UST to be used for any tank smaller than the tank used in the evaluation and any tank whose product surface area (PSA) is less 250% of the PSA of the evaluation tank. Second, it was desired to demonstrate that the system can be used in any type of tank owned by DoD. There are two basic types of ASTs: (1) fixed-roof tanks and (2) fixed-roof tanks with floating pans. Thus, two DEM/VAL sites were used, one with each type of tank. Third, the tanks used in the DEM/VALs had to be free of leaks, and it was desired that no inflow or outflow due to leaking valves occur during the evaluation. Two DoD facilities offered the use of their ASTs for the evaluation: (1) FISC Pearl Harbor and (2) Fairchild Air Force Base.

The FISC Pearl Harbor site was selected for the third-party evaluation, because of the (1) the large size of the tanks storing fuel, (2) the valves isolating the tanks from the transfer piping were new double-block and bleed valves whose the integrity could be verified, (3) it was the most common type of AST owned and operated by DoD, and (4) the need and interest of the fuel farm for a cost-effective system for testing the tanks at the facility. The Fairchild AFB site was selected for the DEM/VAL, because the site had fixed-roof tanks contained floating pans, and there was on-site support and interest in fielding a DEM/VAL.

Figure 2. Photograph of the FISC Pearl Harbor tank used to evaluate the LRDP system. The 8-in.-opening with part of the LRDP mount in place and the bottom catch basket to keep the LRDP stable are shown in the photograph on the left and right, respectively.

3.3 Test Facility History/Characteristics

A brief description of the FISC Pearl Harbor and Fairchild AFB DEM/VAL sites is provided below. For more details, see the ESTCP Demonstration Plan [4].

3.3.1 DEM/VAL 1: Fairchild Air Force Base

The first DEM/VAL was conducted on Tank #2 of the KC-135 Hydrant Fueling system that is adjacent to Pump House B. The tank is a 10,000-barrel (400,000 gal), 54-ft-diameter, fixed-roof AST (with a floating pan) at Fairchild AFB, Spokane, Washington. The main objective was to demonstrate that a fixed-roof AST with a floating pan could be reliably tested without resting the floating pan on its legs at the bottom of the tank.

3.3.2 DEM/VAL 2: FISC Pearl Harbor (Third-Party Evaluation)

The second DEM/VAL was conducted on Tank #56, a 150,000-barrel (6,470,000-gal), 164.5-ft-diameter fixed-roof AST at Pearl Harbor, Hawaii and is one of the largest field-erected bulk

ASTs owned by DoD. The tank is 164.5 ft in diameter and was filled to a depth of 40.7 ft. It contained 6,470,000 gals of JP-5 fuel. The product surface area (PSA) of the tank is 21,253 ft^2. Level changes in this tank are converted to volume changes using a height-to-volume conversion (HVC) factor of 13,248.6 gal/in. The sensitivity of the LRDP to product transfers in and out of the tank was tested by removing from the tank and then adding back over 2,500,000-gal of fuel.

3.4 Testing and Evaluation Plan

The first DEM/VAL was conducted on a 54-ft-diameter, fixed-roof AST at Fairchild Air Force Base This tank was used because it contained a floating pan. The second DEM/VAL was conducted on a 164.5-ft diameter, fixed roof AST at FISC Pearl Harbor. This tank was used because it is one of the largest ASTs owned by the DOD. Both tanks have vertical walls and a sloping bottom. The third-party evaluation was performed on the larger tank. The tests performed on the smaller tank were used to verify that the floating pan did not interfere with a leak-detection test.

3.4.1 DEM/VAL 1: Fairchild Air Force Base

The primary objective of the DEM/VAL conducted at the Fairchild Air Force Base was to demonstrate that the system could be used to test fixed-roof tanks with floating pans for leaks. The LRDP was installed in the tank and checked out during the last week in September 2001. Representatives from Vista Engineering Technologies and Vista Research were present for the installation (and the removal). Approximately five months of data were collected to check out the LRDP and verify its operation in a tank with a floating pan. The tank contained 400,000 gal (95% of capacity) of JP-5 for these tests.

Figure 1 shows the LRDP being installed in the tank through the standard 8-in.opening in the top of the tank. The reference tube was installed in the 8-in.-diameter measurement fill tube. The fill tube extends from the top of the tank to the bottom of the tank and was located approximately one-third of the distance from the wall to the center of the tank. The bottom elevation of the fill tube is at the same elevation as the ground at the side of the tank. The bottom of the tank has about a 5 degree slope, which means the bottom of the tanks is about 28 in. lower in elevation than the bottom of the fill tube. In this configuration, a differential pressure sensor will not completely compensate for the thermal expansion or contraction of the fuel because of the fuel below the pressure sensor. This problem could have been addressed by locating a temperature sensor at the bottom of the reference tube or by installing the reference tube at the center of the tank and appropriately shaping the bottom 3-ft of the tube to match the changing cross-sectional area of the tank. This was done for the tank at FISC Pearl Harbor.

Three types of tests were conducted. The first and most important test was to demonstrate that accurate level measurements could be made in a fixed-roof tank with a floating pan. A calibration test was performed. Measured volumes of product were removed from the tank and compared to the volumes measured with the LRDP using the HVC of the tank. The second test was to investigate the thermally induced volume changes of the wall. This was done using temperature sensors mounted to the external wall of the tank at the North, Southeast and Southwest sides of the tank. The third type of test was to conduct a leak detection test.

The floating pan could degrade a test in two ways. First, the pan could partially stick on the side of the wall during a test. When the floating pan moves freely, the HVC is determined by the cross-section geometry of the product surface. If the pan sticks, the measured HVC would be many of orders of magnitude larger than the actual HVC for the entire tank. Thus, when the pan is stuck, even small volume changes would produce excessively large height changes because of the small product surface area available for vertical movement as compared to the product surface area of the tank itself. As a consequence, it is relatively easy to identify any sticking of the pan. A leak detection test can be performed, even if the pan temporarily sticks during the test, if the pan is freely moving at the beginning and end of the test, or if the pan is stuck during the entire test and the actual HVC has been measured for this condition. In any other condition it is difficult to assess the volume change during the transition periods.

3.4.2 DEM/VAL 2: FISC Pearl Harbor (Third-Party Evaluation)

The LRDP was installed in the tank and checked out during the second week of May 2002. Representatives from Ken Wilcox Associates, Inc., (KWA), Vista Research, Inc., and Vista Engineering Technologies, L.L.C., were present. The LRDP was installed in an 8-in. opening at the center of the tank (Figure 2). A special catch basket was installed in the tank when the tank was cleaned to insure that the LRDP did not move when the transfer pumps, which were aimed directly at the LRDP, were turned on. The bottom 3 ft of the reference tube was shaped to mimic the changing cross sectional area at the bottom of the tank due to the sloping bottom. The same tripod installation system was used on the FISC Pearl Harbor tank that was used on the Fairchild tank. The LRDP was installed and checked out in a day. The data from two 10-day data-collection periods were obtained in May and early June before the start of the evaluation to verify the system was function properly.

Two sets of pre-demonstration tests were conducted between May 20, 2002 and 18 June 2002 before beginning the third party evaluation. These tests were used to verify that the system was performing properly. The leak detection tests used in the evaluation were conducted between June 19 and August 29, 2002.

3.5 Selection of Analytical/Testing Methods

The third-party evaluation of the LRDP was conducted by Ken Wilcox Associates in accordance with a protocol develop especially for ASTs by KWA [33] that is consistent with the protocol developed previously by KWA and used for bulk USTs [12]. This evaluation test procedure follows EPA and ASTM standards for conducting and reporting the results of a third-party evaluation [13, 33]. These standards describe the means for demonstrating the performance of bulk tank leak detection systems.

The tests used in the third-party evaluation were collected by KWA between June 19 and August 29, 2002. Twenty-four (24) tests were conducted, during which KWA randomly introduced leaks ranging from 0.0 to 2.0 gallons per hour. Neither the presence of the leaks nor their size was known to the vendor until after the completion of all of the evaluation tests and all of the test results had been reported.

KWA also examined whether the LRDP was sensitive to effects related to the filling of the tank; the results of the evaluation showed no adverse impact on the performance of the LRDP even if a test was started immediately after the tank had been filled.

The bulk AST evaluation protocol [33] is similar to the bulk UST protocol [12]. The two major differences between the evaluation protocols. First, 24 tests were required by the AST protocol vice 12 tests for the UST protocol. Second, the requirement for at least six transfers was eliminated, because such transfers do not affect mass-measurement systems. However, to demonstrate this, a special removal and addition of fuel to simulate a transfer was conducted. The addition tests were added to get a more representative set of ambient conditions than would be provided with only 12 tests and is consistent with the UST protocols for shop-constructed USTs.

The evaluation procedure requires that the evaluation be performed when the tank is approximately 90% of capacity. Leaks were produced by pumping fuel out of the tank with a peristaltic pump. The protocol requires at least six leaks. Eleven leaks were generated by KWA. Leaks of approximately 0.5, 1.0, and 2.0 gal/h were randomly induced during the evaluation. This blind testing insures the integrity of the evaluation.

Testing during the evaluation was accomplished by KWA personnel following the LRDP testing procedures specified by NFESC and Vista Engineering. Leak simulations and fuel deliveries were defined and monitored by KWA. Leaks were induced by KWA with a peristaltic pump through a valve located on the side of the tank. The LRDP system routinely monitored the results of each test. The output of each test was automatically output from the system. A test duration of 20 h was used. A shorter test duration than 24 h allowed a new test condition to be generated each day.

For bulk ASTs, the LRDP requires that a test be started and completed during darkness. Starting and ending the test at night minimizes the thermally induced changes to the wall of the tank and allows a single temperature sensor to be used for compensation. Accordingly, during the evaluation, KWA changed the induced leak rate each day at 0400. Induced leaks were generated for the first 11 tests. Given that it could take KWA anywhere between several minutes and up to 30 min to change the leak, Vista Engineering started and ended the test at 0530 and 0200, respectively. This insured that the induced leak had been established for each test. No interruptions to the testing occurred during the evaluation.

For each test, the volume rate measured by the LRDP system was compared to the leak rate induced by KWA. Neither the nominal nor actual leak rate was made known to NFESC or Vista Engineering until many months after the evaluation had been completed and the final evaluation report was prepared. Leak rates were calculated from the total mass of fuel removed from the tank during the test and the density of the fuel that was measured with an analytical balance in a laboratory. The mass of the fuel removed from the tank was measured by pumping the fuel into a barrel hanging from a load cell. The uncertainty in the induced leak rates was less than 0.01 gal/h. During each test, KWA also verified the magnitude of the induced leak rate by measuring the pump rate with a graduated cylinder and a stop watch.

The measured volume rates measured by the LRDP are presented in Table 2. As part of the tests, data quality indices automatically checked to verify the quality of the data and to determine whether or not the tank was inadvertently used during the test (e.g., product transfers, or fuel or water sampling). The difference between the measured volume rate and the induced volume rate are also presented in Table 2. The volume rate errors are used to develop the performance of the LRDP system.

Table 2. Summary of the Third Party Evaluation Test Results Obtained in a 164.5-ft-Diameter AST at FISC Pearl Harbor

Start Date At 0530 HST	**End Date** At 0130 HST	**Compensated Test Result (CTR)** (gal/h)	**Induced Leak Rate (ILR)** (gal/h)	**Error = (CTR- ILR)** (gal/h)
6/19/2002	6/20/2002	-0.081	0	-0.081
6/20/2002	6/21/2002	-1.945	-1.902	-0.043
6/21/2002	6/22/2002	-0.214	-0.517	0.303
6/22/2002	6/23/2002	-1.626	-1.066	-0.560
6/23/2002	6/24/2002	Inconclusive	-0.517	
6/24/2002	6/25/2002	-1.801	-1.869	0.068
6/25/2002	6/26/2002	-0.590	-0.851	0.261
6/26/2002	6/27/2002	-1.819	-1.75	-0.069
6/27/2002	6/28/2002	-0.946	-1.364	0.418
6/28/2002	6/29/2002	-0.738	-0.786	0.048
6/29/2002	6/30/2002	-1.403	-0.884	-0.519
6/30/2002	7/1/2002	-0.691	-0.391	-0.300
7/1/2002	7/2/2002	0.113	-0.089	0.202
7/2/2002	7/3/2002	0.295	0	0.295
7/3/2002	7/4/2002	-0.056	0	-0.056
7/4/2002	7/5/2002	-0.084	0	-0.084
7/5/2002	7/6/2002	-0.335	0	-0.335
7/6/2002	7/7/2002	-0.216	0	-0.216
7/7/2002	7/8/2002	0.114	0	0.114
8/23/2002	8/24/2002	0.271	0	0.271
8/24/2002	8/25/2002	0.238	0	0.238
8/25/2002	8/26/2002	-0.112	0	-0.112
8/26/2002	8/27/2002	0.250	0	0.250
8/27/2002	8/28/2002	0.165	0	0.165
8/28/2002	8/29/2002	-0.362	0	-0.362

3.6 Selection of Analytical/Testing Laboratory

The performance of the LRDP was evaluated by Ken Wilcox Associates, Inc., a nationally known third-Party evaluation company for underground and aboveground storage tank and pipeline leak detection systems. The firm has performed several hundred evaluations for a wide range of leak detection systems. Dr. Ken Wilcox and Mr. Jeff Wilcox performed the evaluation. They also performed all three evaluations for the LRDP for bulk USTs.

Their address is

Ken Wilcox Associates, Inc.
1125 Valley Ridge Drive
Grain Valley, Missouri 64029
kwilcox@kwaleak.com
Voice: (816) 443-2494
Fax: (816) 443-2495

4.0 Performance Assessment

4.1 Performance Data

The performance of the LRDP system was assessed for its suitability for both monthly monitoring and for annual or semi-annual precision (tightness) testing of ASTs using the results of many 20-h leak detection tests conducted at both Fairchild Air Force Base and FISC Pearl Harbor. The performance data from the third-party evaluation used to determine whether or not the performance criteria are met are presented in Section 3. Section 4.2 describes the performance criteria and Section 4.3 describes the data assessment.

4.2 Performance Confirmation Methods

The performance criteria of the DEM/VALs were established by the regulatory guidelines developed in California for detection of leaks in *bulk* USTs [32], because quantitative standards for ASTs have yet to be developed, but will be no more stringent than those implemented for bulk USTs. The performance of a leak detection method is evaluated and reported in terms of a probability of detection (P_D) of a target leak rate (TLR) and a probability of false alarm (P_{FA}). At a minimum, the P_D must be equal to or better than 95% and the P_{FA} must be less than or equal to 5%. The TLRs for bulk USTs are typically 0.3 to 1.0 for monthly monitoring when a precision test at 0.2 gal/h is performed annually and 1.0 to 2.0 gal/h for monthly monitoring when the precision test is performed semi-annually. Whether or not the performance criteria are met is determined by a third-party evaluation. The LRDP system was evaluated for a 20-h test duration.

4.3 Data Analysis, Interpretation, and Evaluation

Section 4.3.1 describes the results of the third-party evaluation performed by Ken Wilcox Associates, Inc., (KWA) during the DEM/VAL conducted at FISC Pearl Harbor, and Section 4.3.2 describes the results of the tests conducted during the DEM/VAL conducted at the Fairchild Air Force Base to show that leak detection tests can be performed in fixed-roof ASTs with floating pans.

4.3.1 Third-Party Evaluation Results (FISC Pearl Harbor DEM/VAL)

Ken Wilcox Associates describes the results of two evaluations of the LRDP for detecting leaks in ASTs in two separate final reports, one for the LRDP-24 Version 2 [36-38] and one for the LRDP-24-n Version 2 [39-41]. Five performance estimates are presented for each method, one in the *Final Report* for that method, and four more in a separate volume called *Volume 1: Results Forms*. The test logs are also included, but in another volume called *Volume 2 : Log Sheets*.

4.3.1.1 FISC Pearl Harbor Test Results

An example of the ambient level data measured with the LRDP over a 72-h period is shown in Figure 3. The thermally induced volume changes produced by the thermal expansion and contraction of the tank wall is also shown in Figure 3; the temperature data used to make this estimate were obtained from one RTD mounted on the North wall of the tank. It is clear that the fluctuations in the level data are mainly a function of the thermal expansion and contraction of the wall. However, it is also clear that not all of the level changes measured during a complete diurnal cycle are quantitatively explained by this wall estimate, especially during periods when the sun shines directly on the wall of the tank. As a consequence, as described in Section 2.1, a test is begun and ended at night, when the sun cannot produce uneven heating of one side of the tank or another, and only the change in level from one night-time period to the next is used in the analysis. A test should not be initiated until the entire wall of the tank is uniformly changing temperature. Thus, a test should not be initiated for several hours after sunset. For these measurements, all tests were begun and ended after midnight.

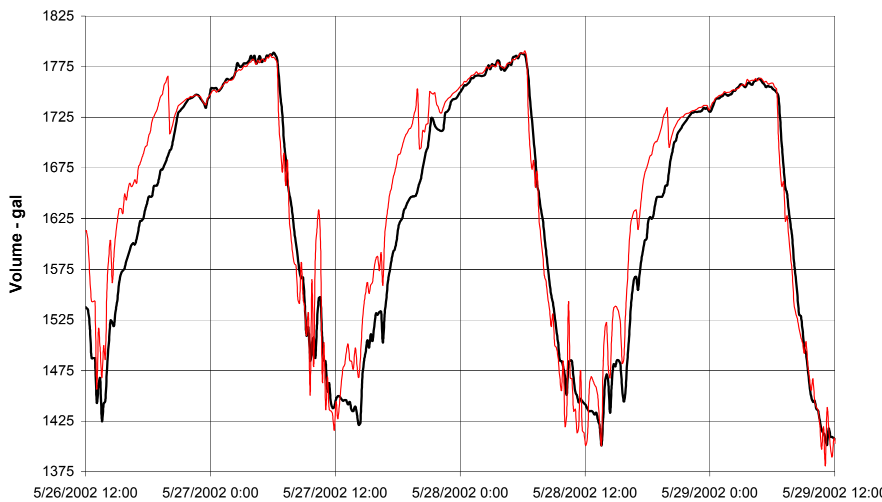

Figure 3. Level and shell-temperature data in gallons that were obtained with the LRDP-24 system during the pre-evaluation LRDP tests.

There are a variety of reasons that might explain the differences between the measured level (volume) changes with the DP sensor and the level (apparent volume) changes produced by the thermally induced wall changes. First, a single temperature sensor is not adequate to fully characterize the wall temperature changes during daylight hours when different sections of the tank (around its circumference) are exposed differently to the sun. Figure 4 illustrates these temperature differences from measurements made on the wall at a spacing of 120°. The temperature differences are larger on the sections of the wall (ESE and WSW) than on the North side of the tank. However, during the night, the temperature measured at all locations are all very similar.

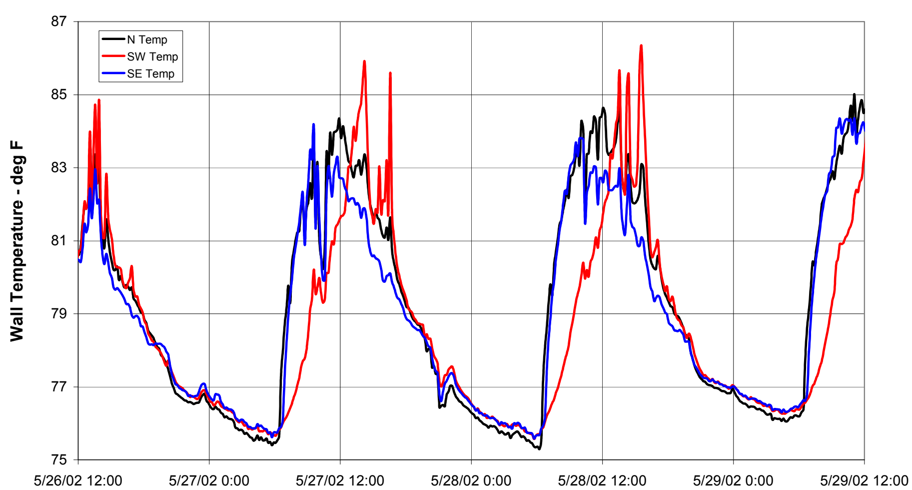

Figure 4. Temperature measurements made at a spacing of 120° (N, ESE, and WSW) during the pre-evaluation LRDP tests.

Second, a model was assumed to compute the volume changes produced by the wall as it thermally expands and contracts due to temperature may not be accurate enough. For the evaluation, it was assumed that the circumference of the tank would change dimension in response to temperature; however, it was assumed that the bottom of the tank was anchored and would not change circumference. This model is generally too simple for accurate prediction throughout a diurnal cycle unless there are an adequate number of temperature sensors placed vertically on the tank at enough positions around the circumference to measure the temperature changes. By starting and ending a leak detection test at night eliminates the affects of uneven solar heating and allows a single temperature sensor to be used.

Third, other sources of error might explain the differences between the level changes and the thermally induced volume changes. Such changes might be produced by thermally induced volume changes of the fuel beneath the DP cell when the DP cell is not located in the bottom of the tank. This "bottom lift" was not a problem during the third party evaluation, because the LRDP was placed on the bottom of the tank, and the reference tube was shaped to match the cross-sectional changes that were present in the bottom three feet of the tank. Temperature data obtained at the bottom of the tank during the third-party evaluation indicated that the shaped tube compensated for the bottom lift. However, such thermally induced volume differences due to bottom lift were observed during the Fairchild AFB DEM/VAL, because the LRDP was not located on the bottom of the tank. In this case, the temperature sensor mounted in the sealed container of the LRDP at the bottom of the tank was used to compensate for the bottom lift.

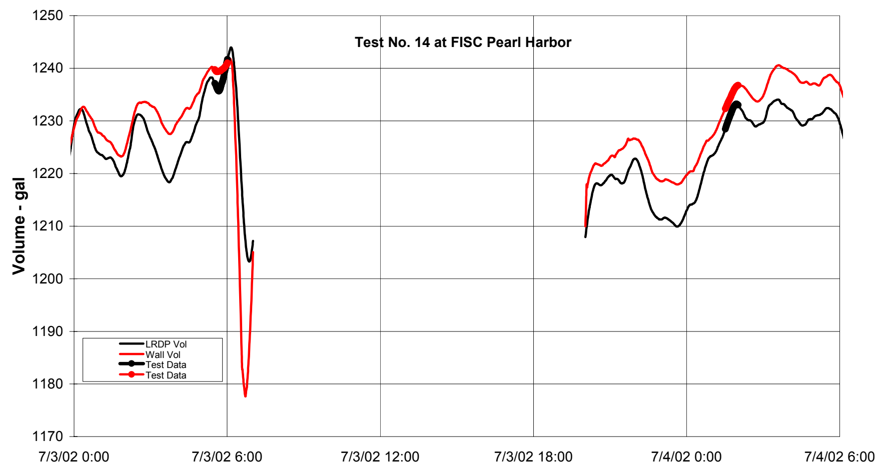

Figure 5. Level and shell-temperature data in gallons that were obtained with the LRDP-24 system for Test No. 14 at FISC Pearl Harbor. No Induced Leak Rate was generated by KWA for the Test. The LRDP measured a volume rate of 0.056 gal/h.

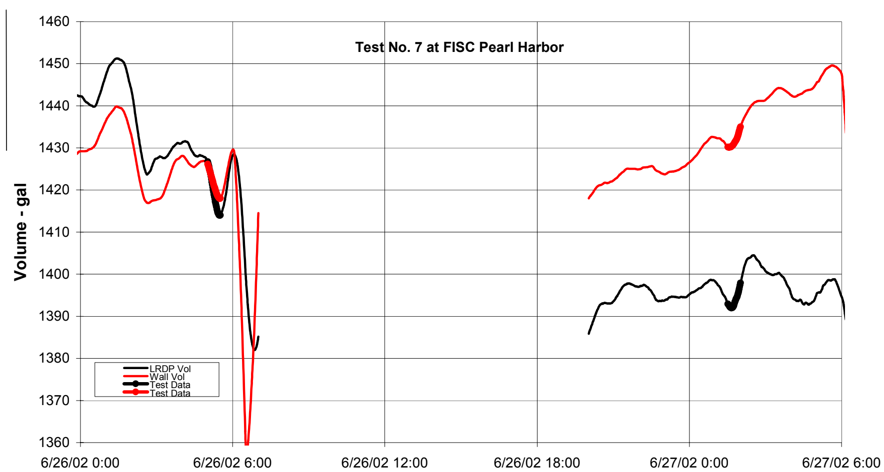

Figure 6. Level and shell-temperature data in gallons that were obtained with the LRDP-24 system for Test No. 7 at FISC Pearl Harbor. The Induced Leak Rate by KWA was 1.75 gal/h and the LRDP measured a volume rate of 1.82 gal/h..

Figures 5 and 6 illustrate the LRDP Volume and Wall Volume time series obtained at the beginning and end of Tests 7 and 14 of the third party evaluation. The 30-min data segments used in the analysis are denoted on the LRDP Volume time series. Test No. 14 illustrates a test without a leak; the LRDP-measured TCVR = 0.056 gal/h, which results in a total difference between the LRDP Volume and the Wall Volume measurements of 1.12 gal. As expected, the 20-h trend of the LRDP Volume and the Wall Volume time series should be closely matched when no leak is present.

However, when a leak is present, there should be a large difference of between the trend of the two time series even though the short-term fluctuations are closely matched. Test No. 7 illustrates this difference. During Test No. 7, KWA induced a leak of 1.75 gal/h; the LRDP-measured TCVR = 1.87 gal/h. As shown in Figure 7, the LRDP Volume and the Wall Volume measurements made at the end of the test are not well matched. A total volume difference between the two 30-min data segments is about 35.4 gal, which is equivalent to 1.87 gal/h when divided by 20 h.

In Figure 3, the level data were converted to volume using the HVC = 13,248.6 gal/in. These data are illustrative of the type of data obtained during the evaluation. It is clear that a test begun at 0530 and ended at 0200 would produce accurate results, but a test begun and ended at noon would not.

The results of the leak detection tests for the LRDP-24 that were presented in Table 2 are summarized graphically in Figure 7. Each test result is plotted against the leak induced for that test. In Figure 7, the test results measured by the LRDP systems appear on the y-axis, while the KWA-induced leak rates appear on the x-axis. A least-squares line has been fitted to the results of the tests with each LRDP system. The slope of the line is nearly 1.0 (1.019 for all 24 of the evaluation tests and 1.012 for the 11 induced leak evaluation tests); this indicates that the volume changes due to the induced leaks are additive with any other volume changes in the tank.

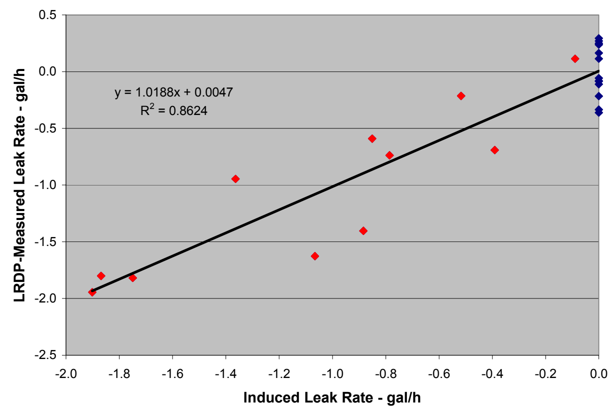

Figure 7. Least-squares lines fitted to the test results of the LRDP-24. The tests conducted with induced leaks are shown in red.

A summary of the statistics of the LRDP-24 determined in the evaluation is presented in Table 3. Table 4 summarizes the statistics of the tests with and without an induced leak. The performance in terms of P_D and P_{FA} are determined from the standard deviation, S, assuming that the histogram of the noise and signal-plus noise are normally distributed. Once the standard deviation is known, the performance can be computed for any P_D and any P_{FA}.

Table 3. Mean and Standard Deviation of the Difference between the Measured Leak Rates (Test Results) and Induced Leak Rates for the LRDP-24

Type of LRDP System	**Number of Tests**	**Mean Volume Rate** (gal/h)	**Standard Deviation** (gal/h)
LRDP-24	24	-0.004	0.272

A statistical hypothesis test was performed using all 24 tests, as required by the evaluation protocol, to determine if the mean was statistically different from zero. A two-sided student-t test was conducted at a level of significance of 0.05. The conclusion of the hypothesis test was that that the mean could not be distinguished statistically from zero, and as a consequence, the method has no bias. This is consistent with the results obtained for the LRDP when used for bulk USTs [5, 8-9, 14-31, 36-41].

Table 4. Mean and Standard Deviation of the Difference between the LRDP-Measured Leak Rates (or Test Results) and the Induced Leak Rates for the LRDP-24

	All Tests	Non-Leak Tests	Induced Leak Tests*
Number of Tests	24	11	13
Average – gal/h	-0.004	0.007	-0.017
Standard Deviation – gal/h	0.272	0.231	0.325
MDLR – gal/h	0.932	0.822	1.179
t_B	0.078	0.103	0.176
Student t (0.05, 2 tails)	2.064	2.160	2.201
Hypothesis Test Result	No Bias	No Bias	No Bias

* The Induced Leak Rate (ILR) is removed by subtracting it from the LRDP-measured value.

The performance of a leak detection system can be affected by the size and geometry of the tank. This relationship is not quantitatively understood for volumetric methods, but is predictable for mass-based systems like the LRDP system. For most mass-based technologies, performance is proportional to the product surface area of the fuel in the tank. According to the evaluation protocol [12, 33], the maximum tank size to which a mass-based method may be applied is determined by the product surface area of the tank, A_{eval}, and is limited to two and one-half times (250%) the surface area of the tank used in the evaluation. Since the surface area of the 164.5-ft diameter, 6,470,000-gal tank used in this evaluation is 21,253 ft^2, the LRDP-24 can be used to test tanks with diameters up to 260 ft. The maximum tank capacity (in terms of volume of fuel in the tank) that can be tested with the LRDP systems is not constrained by the evaluation and will depend on the height of the tank.

4.3.1.2 Performance Estimates for a Single Test (LRDP-24)

Estimates of the performance of the LRDP-24, in terms of P_D and P_{FA}, were generated for the *evaluation tank* from the *standard deviation, S,* given in Table 4. The minimum detectable leak rate (MDLR) is tabulated in Table 5 for the 164.5-ft-diameter evaluation tank and is the leak rate that can be detected with a P_D = 95% and a P_{FA} = 5%. The MDLR is determined from the 24 tests performed in the evaluation by multiplying the standard deviation, S, by 3.428. The 3.428-value is twice the value obtained from a Student's t Distribution table for 23 degrees of freedom and a one-tailed test for a level of significance of 0.05 (see reference [12] for more details).

Table 5. Estimate of the Minimum Detectable Leak Rate (MDLR) for the LRDP-24 in a 164.5-ft Diameter AST

Type of LRDP System	Threshold (gal/h)	Leak Rate (gal/h)	Probability of False Alarm (%)	Probability of Detection (%)
LRDP-24	0.466	0.932	5.0%	95.0%

Four values of the TLR_{eval} were selected to estimate the performance of the LRDP during the third party evaluation: (1) 0.93 gal/h (Version 2.2, MDLR); (2) 1.15 gal/h (Version 2.0, P_{FA} = 1%); (3) 1.86 gal/h (Version (2.1, 2MDLR); (4) 3.5 gal/h (Version 2.0). These TLRs were selected to achieve a certain include certain a P_{FA} for a P_D = 95% and allowed the TLR to scale with tank size without changing the P_D or P_{FA}. For these TLRs, this results in the following P_{FA}s: (1) 5%, (2) 1%, (3) 0.0016%, and (4) very much less than 0.001%. Only four TLRs were selected, because the NWGLDE only allows the performance for four TLRs to be listed, and these four cover the most typical testing requirements in terms of TLR and P_{FA}. (However, other values of TLR are possible if the tank operator needs to operate the system in a specific manner.)

Version 2.2 presents the results for the minimum detectable leak rate (MDLR). Version 2.0 presents the results for a P_{FA} of 1% (and a TLR = 1.15 gal/h). Version 2.0 also presents the results for a TLR = 3.5 gal/h (and a P_{FA} << 0.001%), which was selected to allow monitoring at 1 to 2 gal/h when scaled to the smaller tanks that are typical of most tanks owned by DoD. Version 2.1 presents the results for a TLR equal to twice the MDLR (i.e., 2 MDLR = 2 * 0.932 = 1.86 gal/h), a regulatory guideline for bulk USTs in California. For Versions 2.0, 2.1, and 2.2, the diameter of the tank can be computed for a specific TLR_2 using

$$D = [(TLR/TLR_{eval})\ (n^{0.5})\ (D_{eval}{}^2)]^{\ 0.5} = [(TLR/0.932)\ (n^{0.5})\ (164.5^2)]^{\ 0.5}$$

where the TLR_{eval} is the target leak rate defined for the evaluation tank of diameter D_{eval}. Examples of the performance for different tanks diameters and target leaks rates are presented in the next section.

The formula for computing performance of the LRDP-24 (or the LRDP-24-n, when n = 1) and the LRDP-24-n are summarized in Tables 6 and 7 (and in Appendices D and E) for the various implementations of the method. A general formula and one or more specific implementations of the method evaluated by KWA are presented.

Version 2 of the method, which is summarized in the final reports prepared by KWA allows the user to select a specific TLR for the tank to be tested in such a way that the P_D = 95% and the P_{FA} is less than or equal to 5.0%. The P_{FA} will change for each size tank tested if the same TLR is desired. This implementation allows the operator, for example, to test all ASTs in a fuel farm, regardless of their diameter, at say 1.0 gal/h. This can be done provided that the resulting $P_{FA} \leq$ 5%, which can be calculated using statistical tables.

Table 6. Equations Used to Compute Performance of the LRDP for ASTs by Selecting the Desired TLR for the Test

Method Version No.	**P_D** (%)	**Target Leak Rate*** (gal/h)	**P_{FA}** (%)	**Threshold** (gal/h)
Final Report 2 General	95%	**Select the TLR for a Test** **TLR** provided that $TLR \geq [(MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.2$ or $TLR \geq (0.932/n^{0.5})\ (A/21{,}253) \geq 0.20$	≤ 5.0%	$\mathbf{T = [TLR - (0.5MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.1}$ or $T = [TLR - (0.466/n^{0.5})\ (A/21{,}253)] \geq 0.1$
2 TLR = MDL	95%	$\mathbf{TLR = [(MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.2}$ or $TLR = [(0.932/n^{0.5})\ (A/21{,}253)] \geq 0.2$	5.0%	$\mathbf{T = [0.5MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.1}$ or $T = [0.466/n^{0.5})\ (A/21{,}253)] \geq 0.1$

* The TLR must be greater than or equal to 0.2 gal/h, and the threshold must be greater than or equal to 0.1. If the TLR computed from any of the above formula is less than 0.2 gal/h, then the TLR will be set to 0.2 gal/h and the threshold will be set to 0.1 gal/h. The number of tests ,n, that can be averaged less than or equal to 24 ($1 \leq n \leq 24$).

In general, the regulatory agencies prefer to use implementations of bulk tank leak detection systems where the P_{FA} remains the same for all tank diameters, but the detectable leak rate changes. Versions 2.0, 2.1, and 2.2 are examples. Table 7 presents the equations to compute the target leak rate (TLR) and the threshold, T, for any tank diameter and any number of test averages (up to 24).

Table 7. Equations Used to Compute Performance for the Four Methods (Thresholds) Reported by KWA

Method Version No.	P_D (%)	**Target Leak Rate*** (gal/h)	P_{FA} (%)	**Threshold*** (gal/h)
Result Forms 2.0, 2.1, 2.2 General	95%	**Select the TLR in the Evaluation AST** $\mathbf{TLR = [(TLR_{eval}/n^{0.5})\ (A/A_{eval})]}$ $= [(\alpha\ MDL_{eval}/n^{0.5})\ (A/A_{eval})]$ provided that $TLR \geq [(MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.2$	≤ 5.0%	$\mathbf{T = [((TLR_{eval} - 0.5MDL_{eval})/n^{0.5})\ (A/A_{eval})]}$ $= [(\beta\ MDL_{eval}/n^{0.5})\ (A/A_{eval})] \geq 0.1$
		Four Methods for Use of the LRDP		
2.0 Selected TLR_{eval}s	95%	**TLR** where $TLR \geq (0.93/n^{0.5})\ (A/21{,}253) \geq 0.20$	≤ 5.0%	$\mathbf{T = ((TLR - 0.466)/n^{0.5})(A/21{,}253) \geq 0.10}$
2.0 TLR_{eval} = 1.15	95%	$\mathbf{TLR = 1.15(A/(21{,}253 * n^{0.5})) \geq 0.2}$	≤ 5.0%	$\mathbf{T = ((TLR - 0.466)/n^{0.5})(A/21{,}253) \geq 0.10}$
2.0 TLR_{eval} = 3.5	95%	$\mathbf{TLR = 3.5(A/(21{,}253 * n^{0.5})) \geq 0.2}$	≤ 5.0%	$\mathbf{T = ((TLR - 0.466)/n^{0.5})(A/21{,}253) \geq 0.10}$
2.1 TLR_{eval} = 2 MDL	95%	$\mathbf{TLR = [(2.0MDL_{eval}/n^{0.5})\ (A/A_{eval})]}$ $= (2.00)(0.93/n^{0.5})\ (A/21{,}253)$ $= (1.864/n^{0.5})(A/21{,}253) \geq 0.20$	0.0016 %	$\mathbf{T = (1.50)(0.93/n^{0.5})(A/21{,}253)}$ $= (1.398/n^{0.5})(A/21{,}253) \geq 0.10$
2.2 TLR_{eval} = MDL	95%	$\mathbf{TLR = [(MDL_{eval}/n^{0.5})\ (A/A_{eval})]}$ $= (0.93/n^{0.5})(A/21{,}253) \geq 0.20$	5.0%	$\mathbf{T = (0.466/n^{0.5})(A/21{,}253) \geq 0.10}$

* The TLR must be greater than or equal to 0.2 gal/h, and the threshold must be greater than or equal to 0.1. If the TLR computed from any of the above formula is less than 0.2 gal/h, then the TLR will be set to 0.2 gal/h and the threshold will be set to 0.1 gal/h. The number of tests ,n, that can be averaged less than or equal to 24 ($1 \leq n \leq 24$).

* Four values of the TLR_{eval} were selected to estimate the performance of the LRDP: (1) 0.93 gal/h; (2) 1.15 gal/h; (3) 1.86 gal/h; (4) 3.5 gal/h. The values of α = 1.0, 1.24, 2.0, and 3.76, and β = 0.5, 0.73, 1.50, and 3.26, respectively, for use in computing the TLR and T of the four TLR_{eval}'s specified above.

The variables in Tables 6 and 7 are defined as follows:

$MDLR_{eval}$ = Minimum detectable leak rate of the evaluation tank

MDLR = Minimum detectable leak rate of the tank to be tested

TLR_{eval} = target leak defined of the evaluation tank

TLR = target leak rate defined of the tank to be tested

n = the number of independent tests to be averaged together of the tank to be tested

A_{eval} = Product surface area of the evaluation tank

A = Product surface area of the tank to be tested

T_{eval} = Threshold used to detect the target leak rate, TLR_1, of the evaluation tank

T = Threshold used to detect the target leak rate, TLR_2, of the tank to be tested

D_{eval} = Diameter of the evaluation tank

D = Diameter of the tank to be tested

α is a constant multiplier on MDL_{eval} to compute TLR

β is a constant multiplier on MDL_{eval} to compute T

4.3.1.3 Performance Estimates for More than One Test (LRDP-24-n)

The performance of the LRDP-24 (or any leak detection system) can be improved significantly by combining the results of two or more tests. Averaging two or more test results before applying the threshold will improve *both* the probability of detection and the probability of false alarm over that obtained for a single test. Performance improves as the number of tests averaged together increases. The performance will depend on the test duration and the number of tests, n, averaged together. For example, the performance of the LRDP-24-4 is a factor of 2.0 (square root of 4) times better than a single 20-h test with the LRDP-24; the LRDP-24-4 uses a test duration of 20 h and averages four 20-h tests together.

The performance of the LRDP-24-n systems, where n is the number of independent tests averaged together, is obtained using the *standard deviation of the mean, S_m,* test result, S_m, of the LRDP-24, rather than the *standard deviation, S,* obtained from the evaluation, where S_m, is given by

$$S_m = S / (n)^{0.5} .$$

Averaging is important because it allows all of the bulk ASTs owned or operated by DoD to meet the precision test requirements of 0.2 gal/h.

4.3.1.4 Summary of Performance Results for Different Size Bulk ASTs

Tables 8-12 present the largest diameter tank that can be tested (for the number of tests, n, averaged together) to meet the P_D and P_{FA} specified in the table. The performance results summarized in Table 8 are for the MDLR as a function of tank diameter and the number of tests, n, averaged together. The table indicates the largest tank that can be tested and still maintain the prescribed performance in terms of the P_D and P_{FA}. The performance of the LRDP is proportional to the cross-sectional area of the product surface (i.e., the diameter of the tank) and is inversely proportional to the square root of the number of independent tests averaged together. Thus, the smaller the area (or tank diameter) and the large the number of tests averaged together, the better the performance.

Table 8. Largest Tank Diameter that Can Be Tested with a P_D = 95% and a P_{FA} = 5% as a function of Leak Rate and Number of Tests, n, Averaged Together (Version 2.2)

				n = 1	n = 2	n = 4	n = 6	n = 12
Leak Rate (gal/h)	**Threshold** (gal/h)	**P_D** (%)	**P_{FA}** (%)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)
0.93	0.466	95%	5%	164.5	195.6	232.6	257.5	$\leq$ 260.1
0.20	0.100	95%	5%	76.2	90.6	107.8	119.3	141.8
0.30	0.150	95%	5%	93.3	111.0	132.0	146.1	173.7
0.50	0.250	95%	5%	120.5	143.3	170.4	188.6	224.3
1.00	0.500	95%	5%	170.4	202.6	241.0	$\leq$ 260.1	$\leq$ 260.1
2.00	1.000	95%	5%	241.0	$\leq$ 260.1	$\leq$ 260.1	$\leq$ 260.1	$\leq$ 260.1

The target leak rate used in the evaluation is presented at the top of each table. In Table 8, the MDLR = 0.932 gal/h is presented at the top of the table. Most regulatory agencies require at least this level of performance. In addition, the MDLR is the most straightforward way to compare the performance of different methods. The MDLR attainable in a single test was computed, as well as that attainable by averaging several tests. Since the results of this evaluation are applicable to ASTs with diameters up to 260.1 ft, any computation that would result in the testing of a larger tank diameter is truncated to $\leq$ 260.1 ft.

Table presents the results for Version 2.1, which allows testing at twice the MDLR and maintains a P_{FA} = 0.0016%.

Table 9. Largest Tank Diameter that Can Be Tested with a P_D = 95% and a P_{FA} = 0.0016% as a function of Leak Rate and Number of Tests, n, Averaged Together (Version 2.1)

				n = 1	n = 2	n = 4	n = 6	n = 12
Leak Rate (gal/h)	**Threshold** (gal/h)	P_D (%)	P_{FA} (%)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)
1.86	1.398	95%	0.0016%	164.5	195.6	232.6	257.5	$\leq$ 260.1
0.20	0.150	95%	0.0016%	53.9	64.1	76.2	94.3	100.3
0.30	0.225	95%	0.0016%	66.0	78.5	93.3	103.3	122.8
0.50	0.375	95%	0.0016%	85.2	101.3	120.5	133.3	158.6
1.00	0.750	95%	0.0016%	120.5	143.3	170.4	188.6	224.3
2.00	1.500	95%	0.0016%	170.4	202.6	241.0	$\leq$ 260.1	$\leq$ 260.1

Tables 10 and 11 summarize the results for the two TLRs selected as part of Version 2.0. Table 11 in interesting because it allows the operator to test at a PFA = 1%. By averaging four tests together, a 97.0-ft-diamster AST can be tested at 0.2 gal/h. If a monthly monitoring test is desired at a TLR = 1.0 gal/h, any tank with a diameter of less than 153.4 ft can be tested with a single test.

Table 10. Largest Tank Diameter that Can Be Tested with a P_D = 95% and a P_{FA} = 1% as a function of Leak Rate and Number of Tests, n, Averaged Together (Version 2.0.1.15)

				n = 1	n = 2	n = 4	n = 6	n = 12
Leak Rate (gal/h)	**Threshold** (gal/h)	P_D (%)	P_{FA} (%)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)
1.15	0.684	95%	1%	164.5	195.6	232.6	257.5	$\leq$ 260.1
0.20	0.119	95%	1%	68.6	81.6	97.0	107.4	127.7
0.30	0.178	95%	1%	84.0	99.9	118.8	131.5	156.4
0.50	0.297	95%	1%	108.5	129.0	153.4	169.8	201.9
1.00	0.595	95%	1%	153.4	182.4	216.9	240.1	$\leq$ 260.1
2.00	1.190	95%	1%	216.9	258.0	$\leq$ 260.1	$\leq$ 260.1	$\leq$ 260.1

Table 11. Largest Tank Diameter that Can Be Tested with a P_D = 95% and a P_{FA} <<0.001% as a function of Leak Rate and Number of Tests, n, Averaged Together (Version 2.0.3.50)

				n = 1	n = 2	n = 4	n = 6	n = 12
Leak Rate (gal/h)	**Threshold** (gal/h)	P_D (%)	P_{FA} (%)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)	**Tank Diameter** (ft)
3.50	3.034	95%	<<0.001%	164.5	195.6	232.6	257.5	$\leq$ 260.1
0.20	0.173	95%	<<0.001%	39.3	46.8	55.6	61.5	73.2
0.30	0.260	95%	<<0.001%	48.2	57.3	68.1	75.4	89.6
0.50	0.433	95%	<<0.001%	62.2	73.9	87.9	97.3	115.7
1.00	0.866	95%	<<0.001%	87.9	104.6	124.4	137.6	163.7
2.00	1.734	95%	<<0.001%	124.4	147.9	175.9	194.6	231.4

While the NWGLDE has not yet decided to list the evaluated leak detection systems for ASTs, it is considering doing so. Appendix F includes the required listings that would be submitted.

4.3.1.5 How to Use the LRDP System

The high performance of the LRDP-24, the capability for averaging tests together, and the capability for permanent installation gives the tank owner or operator great flexibility in developing a testing strategy for meeting monthly monitoring and precision test regulatory requirements. The guiding principle that should be used when developing a testing strategy is to minimize the probability of a false alarm while keeping the P_D at 95%. Any P_{FA} that is less than 5% will suffice, but it is highly desirable to have the $P_{FA} < 1\%$ or $<<1\%$.

The exact option to select for the tank owner/operator to use will depend on the size of bulk ASTs at the facility. The provider of the LRDP can help the tank owner/operator design a testing program that is best for the facility. The first step in the design process is to determine which LRDP method (version) should be used for monitoring and which LRDP method can be used for precision testing so that the fewest tests need to be averaged and an acceptable P_{FA} is establsihed. Once this is completed, a test protocol which uses the minimum number of testing combinations (methods and versions) should be selected. The added time required to design the testing program in the beginning will have great benefits once it is implemented.

As an example, suppose a tank owner wants to perform a monthly monitoring test and one annual precision test at 0.2 gal/h on a 70-ft-diameter AST at a P_D = 95% and *at a very low P_{FA}*. Let's assume that a P_{FA} = 0.0016% will suffice. Using Table 9, it is clear that the operator can perform a test at a TLR between 0.3 and 0.5 gal/h and still achieve the desired P_D and P_{FA} in each test performed. However, it would be prudent to operate the system at a higher TLR to avoid problems with small valve leaks. So, the operator might select a TLR = 1.0 gal/h for each monthly monitoring test. Clearly, this will suffice on a 70-ft tank because it will achieve the desired performance in a 120.5-ft-diameter tank. In fact, using a threshold of 0.750 gal/h, which is designed for use with a 120.5-ft tank, will actually result in a P_{FA}< 0.0016% for the 70-ft tank. If the tank owner wishes to perform a precision test at 0.2 gal/h, 3 to 4 tests will have to be averaged together. Table 9 shows that to detect a 0.2-gal/h, n = 4 tests are required if the tank is 76.2 ft in diameter. Thus, to meet the tank owner's requirements, a 1.0 gal/h test could be performed monthly to meet the monthly monitoring requirement, and four of these same tests could be averaged together to meet the annual precision test at 0.2 gal/h. One of the test conducted during each quarter could be used, or the last four tests might be used. More accurate calculations could have been performed to see if n = 3 tests would suffice for the precision test and to determine the true P_{FA} of the monthly monitoring test.

4.3.2 Results of the DEM/VAL of the LRDP in a Fixed Roof-Tank with a Floating Pan

Results from the Fairchild AFB DEM/VAL are presented below. The main purpose of this DEM/VAL was to demonstrate that a fixed-roof AST with a float pan could be tested with the LRDP. A calibration test was performed in which a known volume of fuel was withdrawn from the tank. Nominal volumes of 2, 5, 10, and 15 gal were withdrawn. Figure 8 shows the LRDP-measured level change in inches during the calibration test. The volume of fuel withdrawn is annotated on the figure. For a 54-ft-diameter tank, the geometrical or theoretical estimate of the height-to-volume calibration (HVC) for the tank would be 1,427.7 gal/in. Thus, theoretically, a

10-gal withdrawal should result in a 0.0070-in. level change, which is about the level shown in Figure 8 for this volume of withdrawal. If the pan stuck and only had two 8-in.-diameter openings and a 6-in. annual between the floating pan and the inside wall of the tank, the geometrical HVC with the pan stuck would be 26.75 gal/in. This is 53.4 times smaller than the expected HVC of the tank. Thus, a 10-gal withdrawal would result in a 0.374-level change if the pan was stuck and did not freely float during the withdrawal. Because a tank operator would assume that the pan does not stick, the geometrical HVC of 1,427.7-gal/in. f be applied, and the actual 10-gal withdrawal would appear to produce a 533.7 gal change. Thus, it should be fairly obvious to the tank operator if the pan sticks during a test.

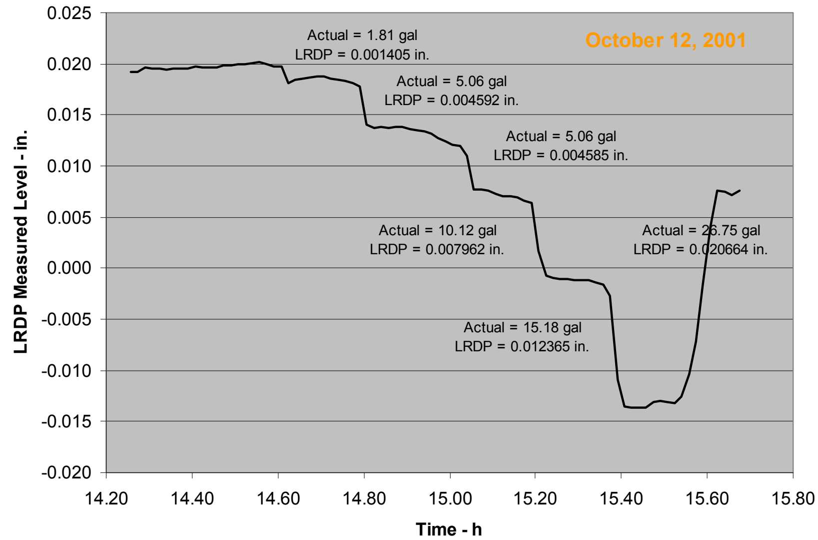

Figure 8. Height-to-volume calibration test results for the 54-ft-diameter fixed-roof AST with a floating pan at Fairchild Air Force Base.

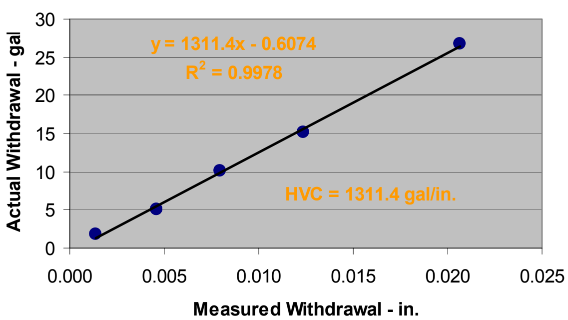

Figure 9. Computation of the HVC from the calibration measurements shown in Figure 7. The measured HVC = 1311.4 gal/in.

There are two interesting observations about the withdrawals in Figure 8. First, small level changes are easily measured. Even the 1.8-gal withdrawal, which should produce a 0.0012-in. level change, is easily discernible. Second, all of the withdrawals seem to produce level changes that are slightly higher than expected. The 10-gal withdrawal produces a 0.0079-in. change vice the expected 0.007-in. change.

Figure 9 shows a plot of the actual withdrawal versus the LRDP-measured level change. The slope of the line, 1,311.4 gal/in, gives the HVC for the tank, which is 8.1% lower than the geometrical calibration. While such an error is not unreasonable for a field check of the HVC, especially if the diameter of the tank is less than 54.0 ft, it is likely that this difference is partially due to some drag due to the sealing skirt at the pan perimeter and any guides used to prevent pan rotation.

Figure 10 illustrates the results of the first test conduced by KWA.

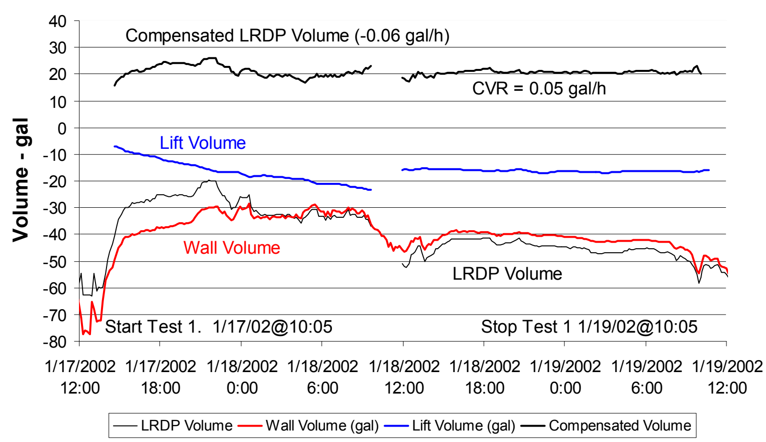

Figure 10. Results of the first test conducted by KWA without introducing an induced leak.

The LRDP-measured volume and the Wall Volume shown in Figure 7 do not closely trend together during the period from 1500 to 2400 on 17 January 2002. This deviation is due to the thermal expansion and contraction of the fuel at the bottom of the tank that was beneath the bottom of the LRDP system (i.e., the Lift Volume). This source of error was compensated in the AST used for the third-party evaluation by placing the LRDP on the bottom of the tank and shaping the tube [42]. At Fairchild, an estimate of the Lift Volume was computed using the temperature sensor on the DP sensor, which is located inside the sealed container. The TCVR, which is obtained after removing the Wall Volume and the Lift Volume from the LRDP-measured Volume, is also shown. The TCVR is -0.06 gal/h, which results in a Pass, because the TCVR is less than the threshold T.

It was our original intention to perform part of the AST evaluation on the AST at Fairchild AFB and part of the evaluation at FISC Pearl Harbor. However, this was not done for several reasons. First, the tank is only 54 ft in diameter and the evaluation would not cover most of the tanks owned by DoD. For bulk USTs, the evaluation mass-based measurement systems for product surface areas up to 250% of the product surface area of the evaluation tank. This would allow the LRDP to be used on ASTs with diameters up to 85 ft. However, there was a concern that the NWGLDE, when it reviewed the AST protocol for approval, might only allow the product surface area to be scaled to 150%, which would only allow the LRDP to be used on ASTs with diameters up to 66 ft. It was also a greater concern that if part of the evaluation were performed with a 54-ft-diameter tank and half of the evaluation were performed with a 164.5-ft-diameter tank, that the tank-size limitation computed by the NWGLDE would be less than the 164.5-ft diameter. Thus, the 54-ft-diameter tank was not formally included in the evaluation.

Second, the bottom port of the DP cell in the LRDP was over 2 ft off the bottom of the tank, and during the night-time period, the measured volume changes with the LRDP and the thermally induced volumes changes produced by the wall (Wall Volume) did not match closely match, as expected, during certain parts of the test and even at night. This deviation was due to the thermal expansion and contraction of the fuel on the bottom of the tank that was not compensated by the LRDP system, and an example is shown in Figure 10 from 1500 to 2400 on 17 January 2002. This so called Lift Volume, while small, would have resulted in an error not representative of the LRDP performance.

5.0 Cost Assessment

This section summarizes the cost and cost savings achievable with the LRDP for testing bulk ASTs. This section also compares the cost of the LRDP to other in-tank mass-based systems, both in-tank ATGs and portable testing-service systems, and to external tracer-based systems. The cost advantages of the LRDP are realized because of the extremely high performance of the LRDP, the on-line monitoring capability of the LRDP when permanently installed in a tank, the capability of the system to conduct a short test (less than 24 h), and the low recurring costs associated with routine testing to address regulatory requirements. And as explained below, the cost savings are significant.

5.1 Cost Reporting

Two DEM/VALs of the technology were conducted. The approximate costs of these DEM/VALs are summarized in Table 12 The first DEM/VAL was to install an LRDP system in a 10,000-bbl (420,000-gal) bulk AST at the Fairchild Air Force Base, Spokane, Washington and to conduct a series of tests to demonstrate that accurate leak detection tests could be performed in a fixed-0roof tank with a floating pan. In the second DEM/VAL, a third-party evaluation of the LRDP was performed in a 150,000-bbl (6,470,000-gal) fixed-roof AST at FISC Pearl Harbor, Hawaii, the largest diameter AST owned by the DoD. The same LRDP system was used for both DEM/VALs. The DEM/VAL costs include an initial site visit, installation, checkout, and removal of the equipment, and conduct of the DEM/VAL (data collection, analysis, and briefing of the results). The DEM/VAL at Fairchild AFB required the collection of data over a 4-month period. The DEM/VAL at FISC Pearl Harbor required the collection of data over a 4-month period; the data for the third-party evaluation was collected between 19 June 2003 and 29 August 2003.

Table 12 Summary of the Costs of the Two DEM/VALs of the LRDP System

DEM/VAL	Cost of the DEM/VAL	Cost of the Third-Party Evaluation	Total
Fairchild Air Force Base	$75,000	$20,000	$950,000
FISC Pearl Harbor	$75,000	$25,000	$100,000
Total	**$150,000**	**$45,000**	**$195,000**

5.2 Cost Analysis

The total life-cycle cost of leak detection includes the following items:

- ***Cost of Regulatory Compliance:*** Purchase, installation, and operation of a leak detection system (direct and recurring costs)
- ***Cost Avoidance***
  - ***Fines and Shutdown of Operations:*** Costs associated with fines for not being in compliance and the cost impact on operations and operational readiness. (direct cost)
  - ***Tank Replacement Cost Avoidance:*** Pre-mature replacement of tanks (direct cost)

– ***Remediation/Cleanup Cost Avoidance:*** Clean-up costs due to lack of testing or testing mistakes (direct cost)

- ***Commercialization and Technology Transfer Cost:*** Commercialization of the pre-production system (direct cost)

It is possible to make an estimate of all of these costs, because the performance of the leak detection system is known. The P_D and P_{FA}, which was determined in the third-party evaluation, allow estimates of the cost of testing mistakes, remediation, and tank replacement to be made. The *cost of regulatory compliance* is described below; the costs associated with *cost avoidance* and *commercialization and technology transfer* are described in Section 6.2.

Regulatory compliance will include the costs associated with the purchase, installation, and use of a leak detection system. It is estimated that the DoD owns or operates approximately 4,000 bulk ASTs with capacities greater than 100,000 gal. The life-cycle cost of a leak detection technology is comprised of the elements in Table 13. The Startup costs are fixed costs and

Table 13. Compliance Monitoring Technology Costs for the LRDP on a Per Tank Basis

Direct Environmental Costs				**Recurring or Variable Environmental Costs**			
Startup		**Operation & Maintenance**		**Compliance Testing**		**Testing Mistakes**	
Equipment Cost	$40,000	Equipment Cost	$40,000	Equipment Cost	$40,000	FA Mitigation Remediation	$40,000 $750,000
Activity	**%**	**Activity**	**%**	**Activity**	**%**	**Activity**	**%**
Facility preparation, mobilization	$4,000 (10%)	Labor to operate equipment	$4000 (10%)	Monthly monitoring	$400 (1%)	False alarms (P_{FA} = 1.0%)	$400 (1.0%)
Equipment Design	$4,000 (10%)	Utilities	$800 (2%)	Annual precision testing	$400 (1%)	Missed detections*	$938 (0.125%)
Equipment purchase	$40,000 (100%)	Consumable and supplies	$400 (1%)	Facility shutdown costs for testing	$1,200 (3%)		
Installation	$8,000 (20%)	Equipment maintenance	$2,000 (5%)				
Training of Operators	$2,000 (5%)	Training of operators	$800 (2%)				
Total	**$58,000** **(145%)**	**Total**	**$8,000** **(20%)**	**Total**	**$2,000** **(5%)**	**Total**	**$1,338**

* It is assumed that the P_D = 95% against a TLR = 0.2 gal/h and the number of leaking tanks is 2.5% of the 4,000 bulk ASTs owned by the DoD. While routine testing with the LRDP should decrease the average cost of new remediations, for this calculation, we assumed the average historical remediation cost.

Include the costs associated with the purchase, installation, and operator training. The Operational and Maintenance costs are also fixed, but are small for the LRDP. The recurring costs associated with Compliance Testing and Test Mistakes are also very small, because once the LRDP is permanently installed, a test can be initiated by pressing a start button, and the performance of the LRDP is very high.

In general, it is not the direct costs that control the price of a leak detection system. Rather, the recurring costs of monthly monitoring and annual precision testing tend to control. For poor performing systems with a higher than desired P_{FA}, the cost of testing increases, because

- additional tests with the same system or another system will have to be conducted to distinguish false alarms from leaks,
- site investigation may be required in terms of monitoring wells or uncovering of buried tanks to determine whether or not the tank is actually leaking,
- such false declarations may have to be reported to regulatory authorities with all the ramifications of such a report, and
- the activities required to determine whether or not a failed test is a false alarm will shutdown facility operations until the false alarm can be resolved.

If the P_{FA} is unacceptably too high, operational experience indicates that fuel farm personnel often do not operate or trust the equipment, and thus, leaks may go undetected. This can be very costly because of the remediation costs associated with undetected leaks.

Table 13 summarizes the costs associated with regulatory compliance with the LRDP. A Parts List for the LRDP is presented in Section 6.1.3. The purchase price of an LRDP assumed for this estimate is based on the purchase of 10 in-tank sensor units. Table 13 presents the cost model in terms of a percentage (%) of the equipment purchase price. The costs of false alarms and missed detections are based on an assumed price for additional testing ($500) and an average remediation cost ($750,000 per incident). The average remediation cost is based on 890 remediation jobs performed by the Navy. These two costs are indicated in the table heading. It is assumed that the P_{FA} is 1.0%, and that the probability of a missed detection is $P_{MD} = 1- P_D =$ 5% for a target leak rate of 0.2 gal/h. It is further assumed for this computation that 2.5% of all of the bulk ASTs owned by the military are leaking. Because small leaks can be detected with the LRDP, the large average cost of remediation can be greatly reduced (e.g., 25% of the average cost); for this calculation, however, it is assumed that the cost of remediation is equal to the average cost.

An important cost is the cost of shutdown associated with testing and testing mistakes (false alarm investigations). Since the military is not selling fuel commercially, any short-term or permanent shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. An estimate of $40,000 for a False Alarm mitigation was used in Table 13, resulting in a $400 per tank cost at a P_{FA} of 1.0%. The total cost per tank is $69,340. A cost comparison of the LRDP and tracer and other mass-measurement systems is given in Section 5.3.

5.3 Comparison

The LRDP has several significant cost advantages over other technologies. An estimate of the cost savings realized by the LRDP over three other methodologies is shown in Tables 14 through 16. Method 1 represents an in-tank tracer method with monthly monitoring. It is well documented that this method has a high recurring cost for Compliance Testing. Method 1 assumes that a tracer must be added to the tank; no cost estimate is provided for tracer methods that use constituents in the fuel as tracers, because their performance has been found to be unacceptable. Method 2 is an in-tank, mass-based method that is assumed to have the capability to meet both the annual precision test and the monthly monitoring requirements, but only as a testing service. Method 3 is an in-tank mass-based, automatic tank gauge (ATG) method that only has the capability to meet the monthly monitoring requirements. It is assumed that another method, like the LRDP or the in-tank tracer method is used to meet the annual precision test. No other permanently installed in-tank, mass-based system besides the LRDP has the capability to meet an annual precision test performance standard (at 0.2 gal/h). No specific commercial methods are identified by brand name here. The cost savings achieved with the LRDP over the in-tank tracer method (Method 1) is mainly due to the very much smaller recurring cost of testing with the LRDP than with the tracer method. The main cost savings achieved with the LRDP over other in-tank mass-based methods that can only meet the annual precision and monthly monitoring requirement as a testing service (Method 2) is the large recurring monthly cost of the service. The main cost savings achieved with the LRDP over other in-tank mass-based ATG methods Method 3) is due to the fact that the LRDP can be used to conduct an annual precision test, while the other in-tank systems cannot. The best way to interpret the tables is to examine the relative cost savings between the LRDP and the other methods. The calculation uses the fixed Start-up costs and the recurring Compliance Testing costs from Table 13 for the LRDP.

The cost comparison calculation is done as follows. First, it was assumed that the Startup and O&M costs are the same for all permanently installed methods. Established price lists for bulk leak detection systems are not generally available or extremely meaningful, because most product sales or testing jobs are performed under a unique contract bid. This computation assumes $40,000, which is higher than anticipated for the LRDP and is lower than typically charged for Method 3. This estimate includes the one-time purchase of the equipment for $40,000 (same as for the LRDP), as well as the same operation and maintenance costs, and the same cost of testing and testing mistakes. While the equipment, operation, and maintenance costs are assumed to be the same for the calculation, a one-time purchase of equipment can be as high as $75,000 for other mass-based systems, and the other mass-based methods typically have a higher probability of testing mistakes than the LRDP. Second, a mobilization charge was added for each site visit to conduct a test at a facility for those methods that are based on a testing service. However, the mobilization charge used for the monthly monitoring tests was reduced, as appropriate, over that of the annual visit. Also, the mobilization was the same for each facility, regardless of the number of tanks tested at that facility. Third, the real cost savings of the testing tends to be controlled by the recurring cost of testing (i.e., experienced with a monthly testing service), or the cost of additional testing because of the lack of capability of the method to satisfy *both* the monthly monitoring and the annual precision test. The estimate assumes that 12 monthly tests and one annual precision at 0.2 gal/h are conducted each year. Fourth, there are significant cost savings associated with cost avoidance and remediation/cleanup when accurate and reliable leak detection is being performed. It is safe to say that the DoD would realize significant cost savings (many hundreds of millions of dollar) if any leak detection system was installed and used. However, if a reliable and accurate leak detection system is used, like the LRDP, these savings could be a factor of 2 to 5 times greater. The cost savings that could be realized by cost avoidance and lower remediation costs are *not* included in this calculation. Fifth, this cost comparison does not include the costs of Testing Mistakes. The number of tests to be conducted each year will be increased (1) if the leak detection system is susceptible to false alarms, or (2) if tests need to be repeated, because they are too long and must be prematurely terminated or because they interfere with operations. Again, the LRDP has a real advantage in terms of performance, but this advantage is not included in this comparison.

Table 14 summarizes the cost of the testing a *100-ft-diameter AST* with each of the methods listed for the *first* AST tested at a bulk storage facility and for *additional* ASTs tested at that facility. Table 14 summarizes, as appropriate, the initial purchase and installation of the leak detection system, the cost of performing 12 monthly tests, and the cost of performing an annual precision test. It is assumed that the first test and the mobilization for the first AST tested at a facility, which includes the initial site preparation and/or annual maintenance checkout, costs significantly more than the remaining 11 monthly monitoring tests. The mobilization is applied only to the facility and is the same regardless of the number of ASTs tested at that facility. However, it is also assumed that the mobilization for the monthly tests is reduced over that charged for the first test at a facility. It is also assumed that the first test on any AST tested at that facility may have a different (higher) price than the remaining 11 monthly tests.

Table 14. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for the First and Additional Bulk ASTs at a Single Facility or Fuel Farm for the First Year

	Purchase of System	**Monthly Monitoring**			**Precision Test**	**Total**	**Total**
	Initial Purchase for One UST System	**Cost of 1st Test on Any AST Tested & One Time Facility Mobilization**	**Cost of Each Monthly Test & Mobilization on 1st AST at a Facility**	**Cost of Additional ASTs Tested at a Facility w/o Mobilization**	**Annual Cost of a Precision Test**	**Annual Cost of Compliance for Year 1 for the 1st AST at a Facility**	**Annual Cost of Compliance for Year 1 for Additional ASTs at a Facility**
Method 1 (In-tank Tracer Testing Service/Installation)	0	6,200 & 8,000	3,750 & 4,000	3,750 & 0		99,450	47,450
Method 2 (In-tank Testing Service)	0		8,000 & 8,000	8,000 & 5,000	16,000	159,000	96,000
Method 3 (In-tank ATG)	40,000	480 & 0	480 & 0	480 & 0		61,760	61,760
LRDP	40,000	480 & 0	480 & 0	480 & 0		45,760	45,760
Method 1/LRDP						2.2	1.0
Method 2/LRDP						3.5	2.1
Method 3/LRDP						1.3	1.3

Table 15 summarizes the total cost of meeting the regulatory requirements for a single bulk AST for all four methods. For comparison, the ratio of the cost of each method relative to the LRDP is given in the tables. Clearly, the recurring cost of the monthly tests associated with Methods 1 and 2 dominate the cost of testing. Table 16 summarizes the cost for a fuel farm containing six bulk ASTs. A factor of two cost savings are observed for the two testing-service methods over that of using these methods for testing only one AST at a facility. These cost savings are realized because only one mobilization cost is charged when more than one tank or test is conducted at the same facility. However, the total cost of these methods is still significantly higher than the LRDP, and do not change much more even if 10 or 20 ASTs are tested at a facility. The total cost savings throughout DoD would be significantly higher if all 4,000 ASTs are included in the estimate.

Table 15. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for the First Bulk AST at a Facility Over 1, 3, 5 and 10 Years

Testing Method	**Total Cost of Compliance for**			
	First Year	**Three Years**	**Five Years**	**Ten Years**
Method 1 (In-tank Tracer)	99,450	298,350	497,250	994,500
Method 2 (In-tank Testing Service)	192,000	576,000	960,000	1,920,000
Method 3 (In-tank ATG)	61,760	105,280	148,800	257,600
LRDP	45,760	57,280	68,800	97,600
Method 1/LRDP	1.9	3.1	3.9	5.0
Method 2/LRDP	3.5	8.3	11.6	16.3
Method 3/LRDP	4.2	10.1	14.0	19.7

As presented in Table 15, over a 10-year period, the cost of the two methods (Methods 1 and 2) for testing an AST at a facility requiring monthly tank preparations or monthly visits, when compared to the LRDP, is a factor of 10 to 20 higher than the LRDP when only one AST is tested. When multiple ASTs are tested, as presented in Table 16 for a six-AST facility, the cost saving is a factor of 5 to 10 higher than the LRDP. The LRDP has at least a 3 to 1 advantage over the lower performing in-tank mass-based ATG (Method 3).

The savings of the LRDP compared to Methods 1 and 2 would result in a payback period of less than one year, and the savings compared to Method 3 would result in a payback period of approximately three years, even without including the savings due to fewer tank replacements and lower remediation costs and the inconvenience of having a testing service come in annually.

Table 16. Comparison of the Cost of Testing in Dollars ($) with Monthly Monitoring and an Annual Precision Test for Six Bulk ASTs at a Facility Over 1, 3, 5 and 10 Years

Testing Method	**Total Cost of Compliance for**			
	First Year	**Three Years**	**Five Years**	**Ten Years**
Method 1 (In-tank Tracer)	336,700	1,010,100	1,683,500	3,367,000
Method 2 (In-tank Testing Service)	672,000	2,016,000	3,360,000	6,720,000
Method 3 (In-tank ATG)	370,560	631,680	892,800	1,545,600
LRDP	274,560	343,680	412,800	585,600
Method 1/LRDP	1.9	3.1	3.9	5.0
Method 2/LRDP	2.3	5.6	7.7	10.9
Method 3/LRDP	2.4	5.9	8.1	11.5

6. Technology Implementation

6.1 Cost Observations

DoD owns more than 4,000 ASTs of varying capacities. While the leak detection requirements for ASTs were deferred in EPA's UST regulation issued on 22 September 1988, many of the states have or are in the process of requiring testing of such tanks. Although Federal regulations have deferred ASTs from monthly monitoring and/or annual precision testing, state regulators are now imposing stringent leak-detection requirements. This presents a unique problem for the DoD, because it owns and operates a large number of bulk ASTs, and no online system currently exists that can perform monthly monitoring tests and an annual precision test. The requirement for testing may cost many tens to hundreds of millions of dollars, depending on the testing approach used. In comparison to other technologies, the LRDP can realize significant cost savings for the DoD. The average cost of the LRDP is a factor of 3 to 11 times less than competing technologies.

The cost of compliance and a comparison of the costs between the LRDP and other methods were described in Section 5. A discussion of the additional cost savings that can be realized due to cost avoidance and commercialization/technology transfer is presented in Sections 6.1.1 and 6.1.2.

6.1.1 Cost Avoidance

The magnitude of the cost savings that can be realized by minimizing testing mistakes, managing tank replacement efforts and minimizing remediation/clean-up efforts through early detection of a release is a direct function of the use and performance of the leak detection system. If equipment is used frequently and the performance is high (i.e., the probabilities of false alarm and missed detection are low), then the need to routinely replace tanks can be minimized. They can continue to be used with confidence that they are not leaking, and if a leak develops, that it will be quickly detected. This reduces the volume of fuel released into the ground and the scope and cost of the cleanup. The high performance of the LRDP means that the number of false alarms and missed detections will be much smaller than other technologies. Furthermore, the high performance of the LRDP allows the probability of false alarm of the system to be set to a very low level without sacrificing the detection of small leaks. The other mass-based systems and some tracer-based approaches do not have the performance to operate with a low probability of false alarm. In addition, other mass-based methods must operate at a higher target leak rate. The total cost savings that can be realized by implementing a reliable leak detection program can be $500 million to $1 billion dollars. These cost savings are described below.

Fines and Shutdown of Operations. The cost of testing more than offsets the cost of the fines that may be levied if the tanks are not tested within the specified regulatory guidelines and are out of compliance. Fines may be $25,000 per day per facility, or more. Ultimately, if the bulk ASTs are not in compliance, fuel operations can be shut down. Since the military is not selling fuel, any permanent or short-term shutdown of fueling operations is difficult to quantify in terms of dollars. However, it is unacceptable to shutdown military operations, or to seriously impact operational readiness. Because the LRDP has the performance to perform both the monthly monitoring and the annual precision test, it is the most cost effective way to be in compliance. Because in many instances, an LRDP test can be performed in 20 h rather than the 48 or 72 h required by other methods, the impact on shutdown is significant.

Tank Replacement Cost Avoidance. Most bulk ASTs are expensive to replace; the costs per tank can be many millions to tens of millions of dollars. Replacement costs can be minimized, avoided, or delayed by using accurate and reliable leak detection. The use of accurate and reliable leak detection can justifiably and safely avoid premature replacement of tanks. The cost savings associated with the use of leak detection is very large. If we assume that the cost of replacement is $5 per gallon of stored fuel, it would cost approximately $10,000,000 to replace a 70-ft-diameter AST. The cost of adding a double bottom and interstitial leak detection might be $500,000 as compared to adding an LRDP at $70,000. Regardless, leak detection is an inexpensive alternative to tank replacement.

Remediation/Cleanup Cost Avoidance. The cost of remediation and cleanup are by far the largest costs associated with leaking tanks and clean-up cost avoidance can be the most significant cost savings realized with the purchase, installation and use of reliable leak detection. It is difficult to estimate the portion of the costs associated with clean-up that can be avoided, but it is significant. The Navy has 659 future LUFT sites to clean up and has estimated that the total cost will be $890,000,000. Early detection of leaks can significantly reduce the total cost of cleanup because the concentration and spatial extent of the plume is smaller than it would be if the leak was not detected early.

6.1.2 Commercialization and Technology Transfer

The costs associated with technology transfer and commercialization are relatively low for the LRDP, because the third-party evaluation has already been completed. At the present time, the NWGLDE, which lists properly evaluated leak detection systems for USTs, is not listing leak detection systems for ASTs. This may change in the future, and the LRDP has been evaluated in accordance with the NWGLDE test procedures. One company, Vista Research, Inc., has already commercialized the pre-production system. A product specification sheet is attached as Appendix G.

6.1.3 Cost of the Parts to Manufacture the LRDP

Table 17 summarizes the cost of the parts to assemble an LRDP for an AST. The price of the PLC and the computer are not included.

6.2 Performance Observations

All of the performance objectives of this program were met. The LRDP was successfully demonstrated in two DEM/VALs. The evaluated performance obtained in the third-party evaluation during the DEM/VAL at FISC Pearl Harbor is sufficient to address all of the regulatory requirements for DoD’s bulk ASTs, because it meets the regulatory requirements for bulk USTs. The results of the DEM/VAL on the fixed-roof tank at the Fairchild Air Force Base indicates that the system can be used to test ASTs with floating pans.

Table 17. Parts List for the LRDP for ASTs without the PLC and Computer*

System	Item	Specification	Vendor	Price/ea	Qty	Total Price
In-Tank						
	Differential Pressure Sensor		Rosemount	$1,568	1	$1,568
	Pressure Sensors		Pressure Sys.	$680	2	$1,360
	Indelas Electrical Actuator		Flow Soln.	$252	1	$252
	RTD and Transmitter		Omega	$173	1	$173
	Bellows (1)			$86	1	$86
	Bellows (2)			$181	1	$181
	SS Tubing (1)		Peterson&Marsh	$273	1	$273
	SS Tubing (2)		Peterson&Marsh	$635	1	$635
	Flanges, Ring, Cover		Premier Tool	$1,410	1	$1,410
	Valve		RS Crum	$130	1	$130
					Subtotal:	**$6,068**
Above-Tank						
	DM6430X PC104 DAQ	-40 to 85 deg C	RTD	$845	1	$845
	SKH486DX100 PC104 CPU	Ext. Temp.	RTD	$1,296	1	$1,296
	RTD and Transmitter		Omega	$173	4	$692
	Voltage Reference (AD586)	0 to 70 deg C	Newark	$13	1	$13
					Subtotal:	**$2,846**
	Misc. Electrical					**$644**
	Misc. Mechanical					**$2,692**
					Total Parts:	**$12,250**

* Prices were compiled in 2001.

6.3 Scale-up

The DEM/VALs were all conducted on full-scale, operational aboveground storage tanks. The DEM/VALs were conducted on one, if not the largest diameter AST owned by DoD. The performance of the LRDP in other tanks scales with tank diameter (or equivalently, the product surface area of the fuel in the tank). As the tank diameter decreases, the performance improves and smaller leak rates can be detected. Based on the third party evaluation, the LRDP can be used to test tanks with capacities as small as 50,000 gal and with diameters as large as 260 ft, which includes all of the ASTs owned by DoD, and all but a few of the ASTs that exist in the petroleum industry.

6.4 Other Significant Observations

All tank operations must cease during a test; no fuel transfers in or out of the tank are allowed. This temporary shutdown of the tank is minimized by the LRDP in comparison to other in-tank leak detection systems, because the duration of the test is shorter than the other methods. The LRDP can meet the monitoring and precision regulatory requirements in a 20-h test. The other technologies typically require 48 to 72 h, and other than the LRDP, none of the permanently mounted in-tank systems have sufficient performance to perform a precision test.

6.5 Lessons Learned

In order to conduct a leak detection test with this technology, the tank must be isolated from the piping associated with the tank. Thus, it is important that all valves at the tank be completely sealed before a test is initiated. This is particularly important when conducting a precision test at 0.2 gal/h. Many of the valves at DoD facilities are double-block and bleed valves, which allow a visual check of the seal and a measurement of the flow across the valve if it does not seal. The monthly monitoring standards are sufficiently large in comparison to the performance of the LRDP that small valve leaks can be tolerated during a test without impacting the results. No waiting period is required for the conduct of a leak detection test with a mass-based system like the LRDP.

6.6 End-User Issues

The LRDP is ready for commercialization and has been evaluated for performance by a third party. Vista Research, Inc., has commercialized the LRDP and is now offering products and services based on the LRDP implemented using a PLC. A product specification sheets is attached in Appendix Gfs. Immediate commercialization of this technology has been possible, because fuel terminal operators were involved during the demonstrations and the bulk storage tank facilities have a real need to address. Some limited sales of the LRDP have already occurred. For example, the LRDP has been used to test an AST at Point Loma and a chemical tank (containing sodium hydroxide) at an industrial facility.

At the request of NFESC, during this ESTCP project, a workshop was conducted by the Environmental Technology Evaluation Center (EvTEC) of the Civil Engineering Research Foundation (CERF) to introduce the technology and to describe the advantages of the system for regulatory compliance [11]. Technical experts and representatives from the petroleum industry, the Defense Energy Support Center (DESC), and the U. S. Air Force, Army, and Navy were present.

6.7 Approach to Regulatory Compliance and Acceptance

At the present time, AST are not strongly regulated and regulatory standards have not been established. It is clear from public and private forums that many states are developing such regulations or regulatory guidelines. SPCC plans and API 653 inspections encourage leak detection but stop short of requiring it. However, the SPCC encourages leak detection testing by allowing an increased interval between inspections. Also, leak detection has been found to be useful in verifying that a tank is leak free before it is brought back into service after an API 653 inspection. As a consequence, the evaluation was conducted and the results of the evaluation were reported to meet the two practical regulatory guidelines for using in-tank mass-based measurements in California for bulk USTs, which were developed and recommended by NFESC and Vista Research (Options 7 and 10).

It was assumed that the regulatory requirements for ASTs would be similar and no more stringent than those for bulk USTs [32]. Option 7 requires monthly monitoring tests with a system capable of detecting a leak between 1.0 and 2.0 gal/h with a $P_D \geq 95\%$ and a $P_{FA} \leq 5\%$, and a semi-annual precision test with a method capable of detecting a leak of 0.2 gal/h with the same P_D and P_{FA} as for the monthly monitoring test. Option 10 is similar to Option 7, except the monthly monitoring criteria is 0.3 to 1.0 gal/h, and the precision test need only be conducted annually. While the precision test requirement of 0.2 gal/h is stringent, it is achievable by the LRDP and for many tanks with only a single test. The monthly monitoring requirements of 0.3 to 1.0 gal/h or 1.0 to 2.0 gal/h are operationally practical and easily met by the LRDP.

The approach to regulatory requirement depends on the size of the tank to be tested as was discussed in Section 4. The main recommendation is to operate the system such that the regulatory requirements can be met with the lowest probability of false alarm. Given the choice, the monthly monitoring should be addressed using the largest target leak rate as possible less than 2.0 gal/h. This minimizes any minor system problems that might otherwise interfere with a test (i.e., a small flow across a valve).

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34. Petroleum Institute Standard 653, (API 653) Tank Inspection, Repair, Alteration and Reconstruction, 2nd Edition, including Addendum 1 (December 1996), Addendum 2 (December 1997), Addendum 3 (December 1998), and Addendum 4 (December 1999), December 1995.

35. U.S. Environmental Protection Agency. “40 CFR 112.8 and 112.11 – Spill Prevention, Control, and Countermeasures (SPCC) Regulation.” EPA 540-K-02-006 and OSWER 9360.8-52, October 2002.

36. J. K. Wilcox. “Evaluation of the LRDP-24 on Aboveground Storage Tanks: Final Report.” Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

37. J. K. Wilcox. “Evaluation of the LRDP-24 on Aboveground Storage Tanks : Volume 1. Results Forms.” Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

38. J. K. Wilcox. “Evaluation of the LRDP-24 on Aboveground Storage Tanks: Volume 2. Test Log Sheets.” Third-Party Evaluation Test Log Sheets, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

39. J. K. Wilcox. “Evaluation of the LRDP-24-n on Aboveground Storage Tanks: Final Report.” Third-Party Evaluation Report, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

40. J. K. Wilcox. “Evaluation of the LRDP-24-n on Aboveground Storage: Volume 1. Results Forms.” Third-Party Evaluation EPA Forms, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

41. J. K. Wilcox. “Evaluation of the LRDP-24-n on Aboveground Storage Tanks: Volume 2. Test Log Sheets.” Third-Party Evaluation Test Log Sheets, prepared for the Naval Facilities Engineering Service Center and Vista Research, Inc., prepared by Ken Wilcox Associates, Inc., 1125 Valley Ridge Drive, Grain Valley, MO 64029, 18 December 2002.

42. J. W. Maresca, Jr., “System and Method for Leak Detection in Liquid Storage Tanks.” U. S. Patent No. 4,646,560, Vista Research, Inc., Palo Alto, California, 3 March 1987.

8.0 Points of Contact

The points of contact for this project are presented in Table 17.

Table 17. Points of Contact

Point of Contact	Organization	Phone/Fax/Email	Role in Project
Leslie A. Karr, REM Program Manager	Naval Facilities Engineering Service Center (NFESC) 1100 23rd Avenue Port Hueneme, CA 93043-4370	voice: (805) 982-1618 fax: (805) 982-4304 e-mail: leslie.karr@navy.mil	Project Manager
William R. Major Project Engineer	Naval Facilities Engineering Service Center (NFESC) 1100 23rd Avenue Port Hueneme, CA 93043-4370	voice: (805) 982-1808 fax: (805) 982-4304 e-mail: bill.major@navy.mil	Project Engineer
Dr. Joseph W. Maresca, Jr. Vice President	Vista Research, Inc. 755 North Mary Avenue Sunnyvale, California 94086	voice: (408) 830-3306 fax: (408) 830-3399 e-mail: maresca@vrinc.com	Technical Director, Industry Partner
James W. Starr, P. E. Staff Engineer	Vista Research, Inc. 139 Glendale Avenue Edison, New Jersey 08817	Voice: (732) 777-2100 Fax: (732) 777-9495 e-mail: jstarr@vrinc.com	Project Engineer
Dr. H. Kendall Wilcox President	Ken Wilcox Associates, Inc. 1125 Valley Ridge Drive Grain Valley, MO 64029, USA	voice: (816) 443-2494 fax: (816) 443-2495 e-mail: kwilcox@kwaleak.com	Third-Party Evaluator
Mr. H. Jeffrey Wilcox Engineer	Ken Wilcox Associates, Inc. 1125 Valley Ridge Drive Grain Valley, MO 64029, USA	voice: (816) 443-2494 fax: (816) 443-2495 e-mail: jwilcox@kwaleak.com	Third-Party Evaluator
Col Patrick L. Fink U. S. Air Force	Randolph Air Force Base San Antonio, TX	voice: (210) 652-6375	DEM/VAL Liaison
Jim Gammon FISC, Pearl Harbor	FISC, Pearl Harbor Pearl Harbor, HI	voice: (808) 473-2390 fax: (808) 473-0405 e-mail: james.gammon@navy.mil	DEM/VAL Liaison
Rick Rosa, Civil/Environmental Division Head	Fairchild Air Force Base 92 CES/CEV 100 W. Ent St. Suite 155 Fairchild AFB, WA 99011	voice: (509) 247-8163 fax : (509) 247-4858 e-mail : rick.rosa@fairchild.af.mil	DEM/VAL Liaison
Paul Rodgers	Defense Energy Office – Los Angeles Defense Energy Supply Center (DESC) John J. Kingman Road, Suite 4950 Fort Belvoir, VA22060-6222	voice: (702) 767-8313 fax: (703) 767-8331 e-mail: prodgers@desc.dla.mil	DEM/VAL Liaison
William Middleton	Defense Energy Office – Los Angeles Defense Energy Supply Center (DESC) John J. Kingman Road, Suite 4950 Fort Belvoir, VA22060-6222	voice: (702) 767-8313 fax: (703) 767-8331 e-mail: wmiddleton@desc.dla.mil	DEM/VAL Liaison

Appendix A

Software User Interface Screens

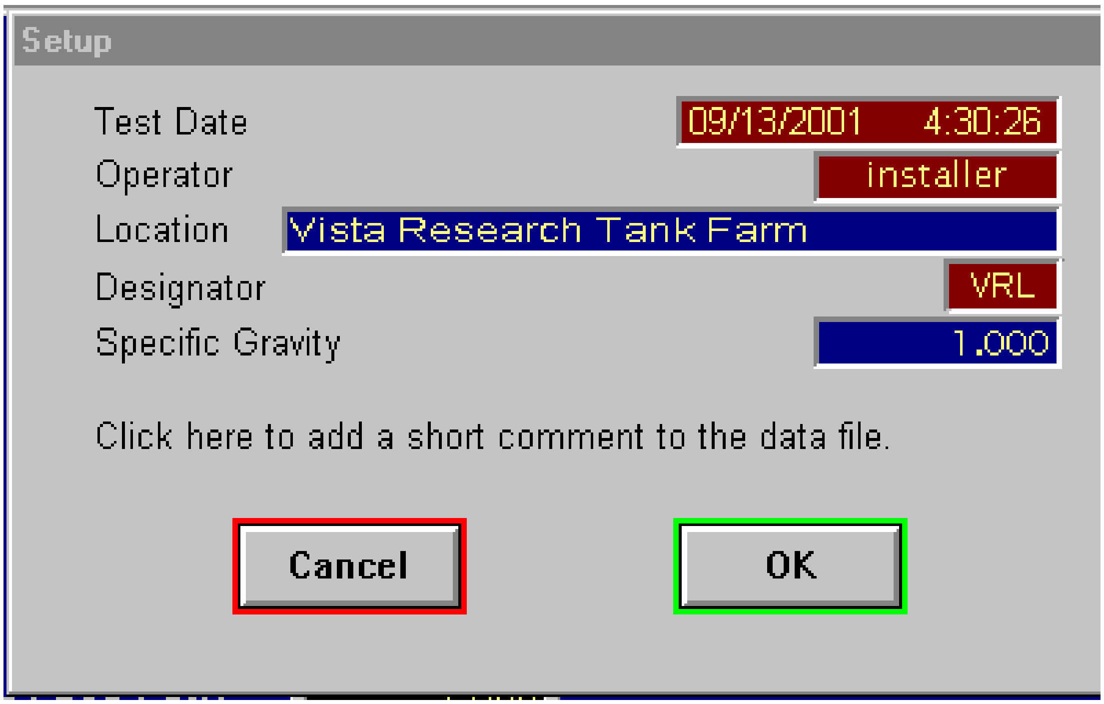

Figure A-1. *LRDP Test Setup Menu:* This screen allows the user to input the test file parameters.

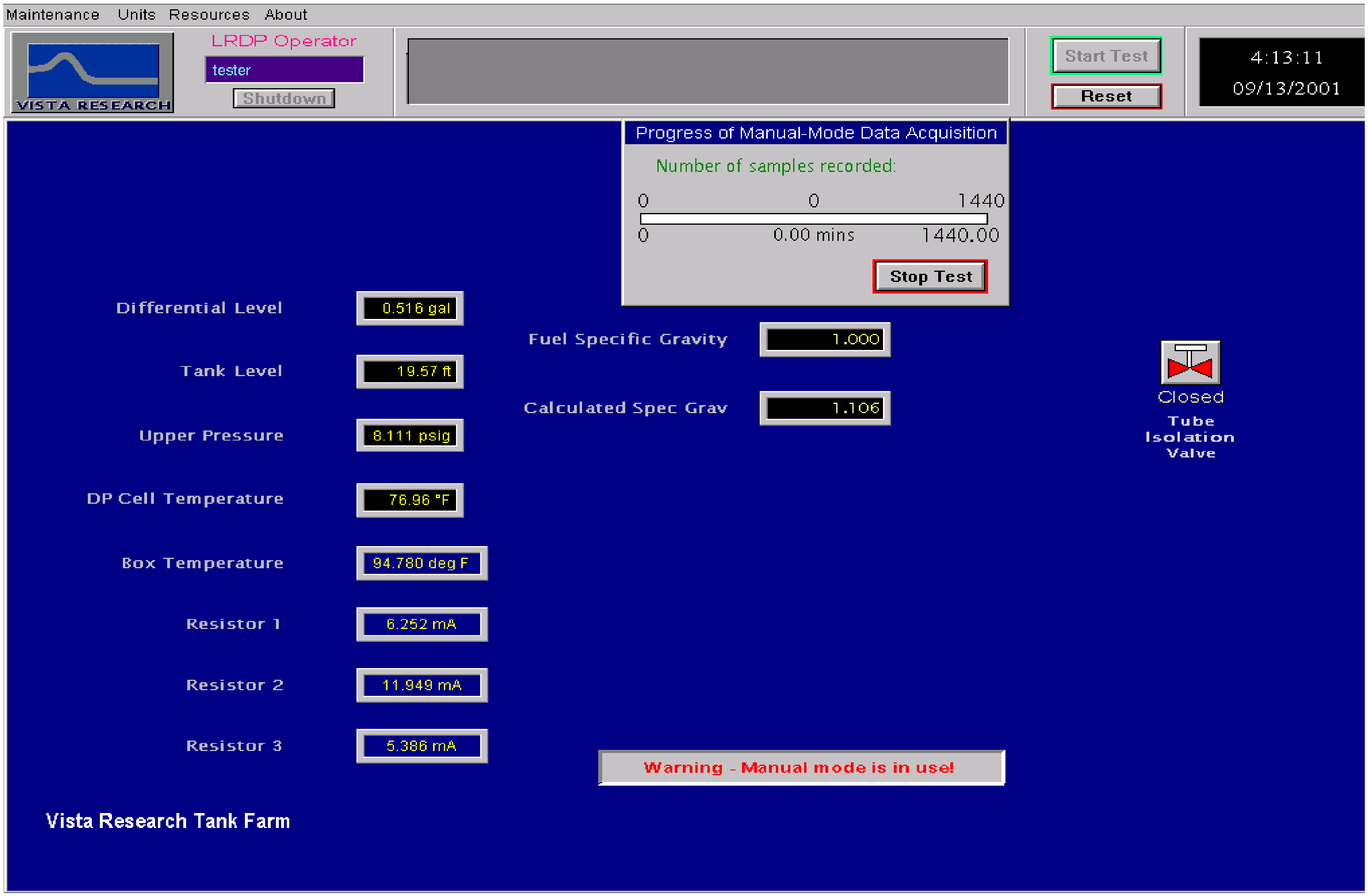

Figure A-2. *LRDP Input/Output PLC Display for the LRD:* This screen allows the user to start and stop a test a leak detection test. It also allows the user to see a real time output of the tank level and the level being measured by the LRDP as part of a leak detection test as well as an output from the other sensors.

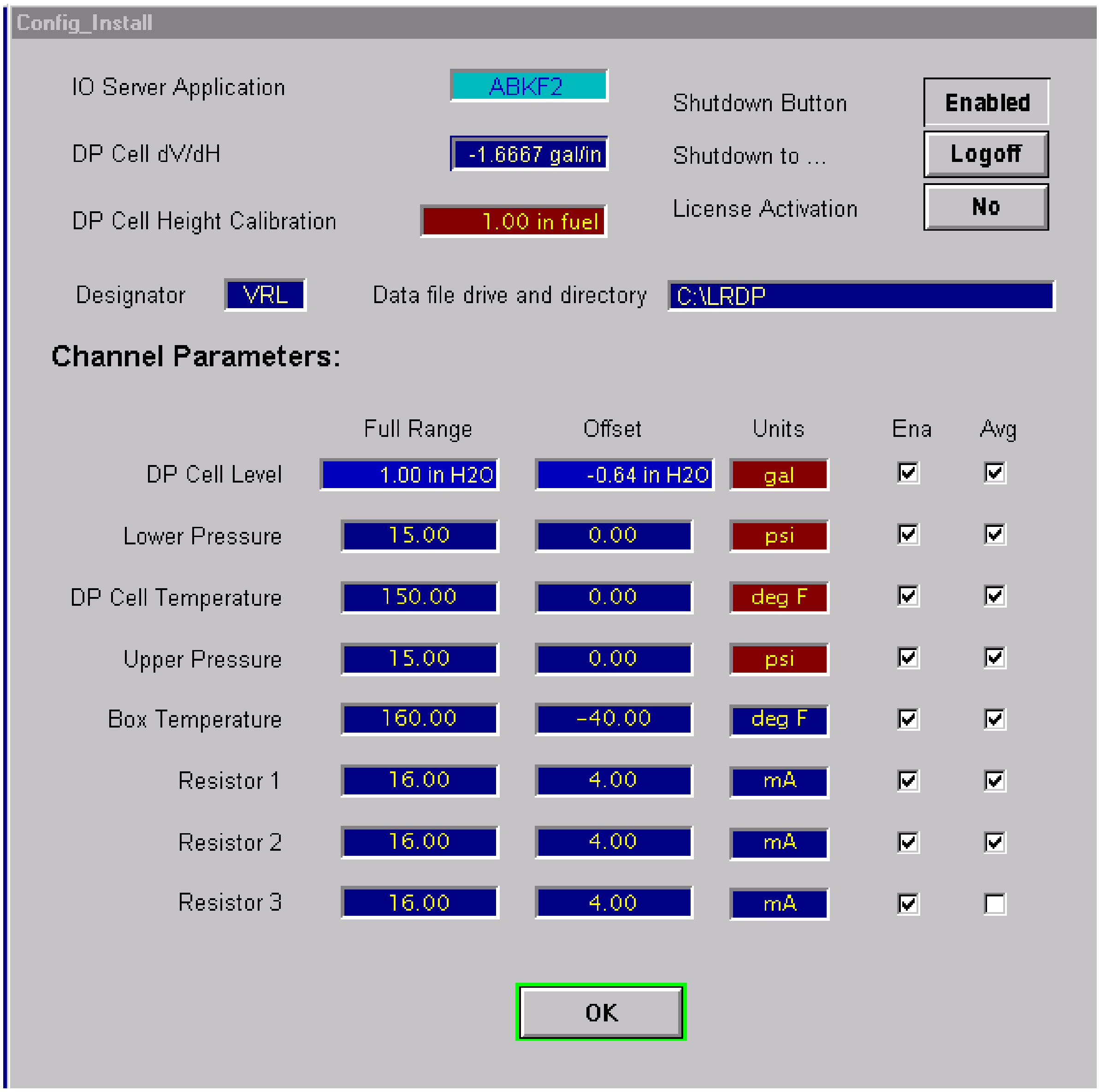

Figure A-3. *LRDP Configuration and Installation Menu:* This screen allows the user to input the sensor configuration and calibration parameters.

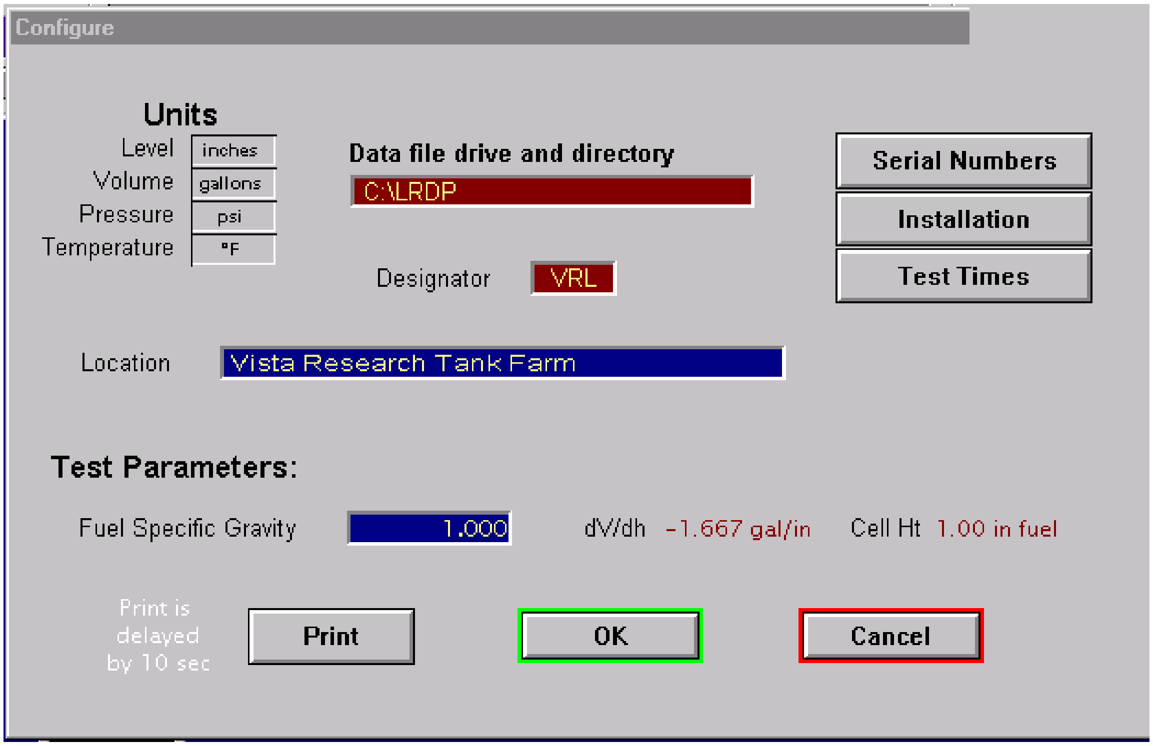

Figure A-4. *LRDP Data File Configuration Menu:* This screen allows the user to input the data file parameters.

Appendix B

Quality Assurance Plan

B.1 Purpose and Scope of the Plan

The purpose of the demonstration QA is to ensure that the following take place:

- That equipment used in the generation, measurement, and assessment of data is of appropriate design and adequate capacity to function properly, is adequately calibrated, and is suitably located for operation and inspection.
- That all protocols pertaining to the demonstrations followed. And that deviations from approved protocols or standard operating procedures are not made without proper documentation.
- That the integrity of each demonstration is ensured. And that written and signed records of each demonstration test show the dates and times of the test, the phase or segment of the demonstration, the person performing the test, any problems, and actions recommended and taken.
- That the demonstration final report accurately describes the methods and standard operating procedures, and that the reported results accurately reflect the data of the demonstration.

The demonstration will be conducted in accordance with the *Standard Test Procedure for Evaluating Leak Detection Methods: Volumetric Tank Test Methods*[4]. The QA provisions of that protocol are consistent with, and will ensure compliance with, the purpose identified above.

B.2 Quality Assurance Responsibilities

Ken Wilcox Associates, Inc. (KWA), an internationally recognized, independent third-party test laboratory, has been retained to conduct the demonstration tests, including quality assurance oversight in accordance with the anticipated EPA protocol. KWA has the responsibility to develop the induced leak rate test schedule (using the experimental design outlined in the EPA test protocol), and to keep the leak rates blind to everyone else. The on-site KWA personnel have the responsibility for providing, setting up, calibrating and maintaining the induced leak rate generating and monitoring equipment, for conducting the tests, and for maintaining the on-site documentation and data records. KWA also has the responsibility to calculate the LRDP system performance and to prepare the reports for submittal for certification.

B.3 Data Quality Parameters

The primary data quality parameters to be determined from these demonstration/certification tests are accuracy and precision. Accuracy refers to the degree of agreement of a measurement to the true value. The calculation procedure of the test protocol quantifies and identifies the accuracy as bias. Precision refers to the reproducibility of the measurements. The test protocol calculations quantify this parameter in the form of a standard deviation. This value then relates the false alarm rate to the leak detection threshold

B.4 Calibration Procedures, Quality Control Checks, and Corrective Action

KWA personnel will check the load cell calibration by incrementally adding known amounts of fuel to the holding tank. The LRDP leak detection system calibration will be checked against the KWA induced leak system in a preliminary test run, as prescribed in the EPA test protocol.

B.5 Demonstration Procedures

Following the initial checkout and the preliminary test run for calibration check, the test sequence will follow the EPA test protocol test schedule, as described in Section 5 of this document. If a problem occurs during a test run, the KWA on-site test administrator will decide whether to continue or abort and restart the test run. All initiated tests will be logged.

B.6 Calculation of Data Quality Indicators

A tank leak detection system is required to measure volumetric leak rate in units of gallons per hour. System detection thresholds on the order of a tenth of a gal/h are being sought. The performance rating of the tank leak detection system is based on the differences between the actual rates and the detected rates. The actual induced leak rates are calculated by multiplying the total mass of the removed fuel times its density, and then dividing by the total run time. The total mass is measured by pumping the induced leak product into a holding tank, which is mounted on a load cell. The load cell and time are read and recorded electronically. Samples are drawn for laboratory measurement of density. Since only the removed fuel is measured, a very accurate measurement can be made with fairly ordinary instrumentation. With the KWA test equipment being used, the uncertainty in the simulated leak rates is estimated at less than 0.01 gal/h.

B.7 Performance and System Audits

The performance rating is based on the differences between the detected and the actual leak rates. It is essential that the tank be sealed during the test runs. A leaky valve or pump will introduce an error in the leak detection system rating. The test protocol requires fuel transfers from-and-to the tank between scheduled test runs. For these large tanks, the only practical method for accomplishing the transfers is through the tank farm piping system. Any leaks through the valves or pumps will compromise the results of a test run. The KWA equipment measures the product removed from the tank for the test induced leak. It does not detect leaky tank valves. The KWA test administrator will make early comparisons of the induced leak and the LRDP detected leak rate to assure that valid test conditions exist.

B.8 Quality Assurance Reports

Each test run involves a comparison of detected and induced leak rates. The test logs, themselves, will serve as quality assurance reports.

Appendix C

Health and Safety Plan

Both demonstration sites are located on military bases. The demonstrations will be conducted in conformance with the Base, EPA, and test agency safety requirements. The Base Safety Officer/Inspector has overall jurisdiction for safety, and will resolve any questions or conflicting requirements. The test agency, Ken Wilcox, Associates, regularly conducts tests of this type. The on-site test agency personnel are familiar with the EPA and KWA safety requirements. The on-site test agency personnel will be briefed by the Base Safety Inspector and will be provided with a copy of the Base Safety Regulations. These regulations will be posted at the test site. On-site safety equipment required by EPA and test agency regulations will be provided by the test agency. Additional safety equipment, if required, will be provided by the government.

Appendix D

Performance Equations for Version 2 of the LRDP-24 and LRDP-24-n

Operation of the Evaluated System

LRDP for ASTs Version 2 Mass Based Systems (with scaling included)	
	Test Threshold *** Set P_D = 95% against a Target Leak Rate $TLR_2 \geq MDL_2$ to insure $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	Select a TLR_2 such that $TLR_2 \geq [MDL_1 (A_2/A_1)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(MDL_1 (A_2/A_1)] < 0.2$
Threshold, T_2 – gal/h	$T_2 = [TLR_2 - C_{MDL\ 1}\ (A_2/A_1)] \geq 0.1$ or $T_2 = 0.1$ when $[TLR_2 - C_{MDL\ 1}\ (A_2/A_1)] < 0.1$
P_D – %	95%
P_{FA} - %	$\leq 5\%$
*The TLR_2 (= target leak rate) is selected for the tank to be tested. **Define MDL_1 and $C_{MDL\ 1} = MDL_1/2$ for A_1; S for A_1; and A_1	

Operation of the Evaluated System

LRDP for ASTs Version 2 Mass Based Systems (with scaling and averaging included)	
	Test Threshold *** Set P_D = 95% against a Target Leak Rate $TLR_2 \geq MDL_2$ to insure $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	Select a TLR_2 such that $TLR_2 \geq [(MDL_1/n^{0.5}) (A_2/A_1)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(MDL_1/n^{0.5}) (A_2/A_1)] < 0.2$ with $1 \leq n \leq 24$
Threshold, T_2 – gal/h	$T_2 = [TLR_2 -(C_{MDL}/n^{0.5}) (A_2/A_1)] \geq 0.1$ $T_2 = 0.1$when $[TLR_2 - (C_{MDL}/n^{0.5})\ (A_2/A_1)] < 0.1$ with $1 \leq n \leq 24$
P_D – %	95%
P_{FA} - %	$\leq 5\%$
*The TLR_2 (= target leak rate) is selected for the tank to be tested. **Define MDL_1 and $C_{MDL\ 1} = MDL_1/2$ for A_1; S for A_1; and A_1; $1 \leq n \leq 24$	

LRDP-24 for ASTs Version 2	
	Test Threshold *,** Set P_D = 95% against a Target Leak Rate $TLR_2 \geq MDL_2$ to insure $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	Select a TLR_2 such that $TLR_2 \geq [0.932\ (A_2/21{,}253)] \geq 0.2$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(0.932\ (A_2/21{,}253)] < 0.2$
Threshold, T_2 – gal/h	$T_2 = [TLR_2 – 0.466\ (A_2/21{,}253)] \geq 0.1$ or $T_2 = 0.1$ when $[TLR_2 – 0.466\ (A_2/21{,}253)] < 0.1$
P_D – %	95%
P_{FA} - %	$\leq$5%
*The TLR_2 (= target leak rate) is selected for the tank to be tested. **MDL_1 = 0.932 gal/h; $C_{MDL\ 1}$ = 0.466; S = 0.272 gal/h; and A_1 = 21,253 ft^2.	

LRDP-24-n for ASTs Version 2	
	Test Threshold *,** Set P_D = 95% against a Target Leak Rate $TLR_2 \geq MDL_2$ To insure $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	Select a TLR_2 such that $TLR_2 \geq [(0.932/n^{0.5})\ (A_2/21{,}253)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(0.932/n^{0.5})\ (A_2/21{,}253)] < 0.2$ with $1 \leq n \leq 24$
Threshold, T_2 – gal/h	$T_2 = [TLR_2 -(0.466/n^{0.5})\ (A_2/21{,}253)] \geq 0.1$ $T_2 = 0.1$when $[TLR_2- (0.466/n^{0.5})\ (A_2/21{,}253)] < 0.1$ with $1 \leq n \leq 24$
P_D – %	95%
P_{FA} - %	$\leq$ 5%
*The TLR_2 (= target leak rate) is selected for the tank to be tested. **MDL_1 = 0.932 gal/h; $C_{MDL\ 1}$ = 0.466; S = 0.272 gal/h; and A_1 = 21,253 ft^2; $1 \leq n \leq 24$.	

Appendix E

Performance Equations for Versions 2.0, 2.1, and 2.2 of the LRDP-24 and LRDP-24-n

Operation of the Evaluated System

Versions 2.0, 2.1, 2.2 Mass Based Systems (with scaling included)	
	Test Threshold *** Set P_D = 95% against a Target Leak Rate $TLR_1 \geq MDL_1$ and insure the $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	$TLR_2 = [TLR_1 (A_2/A_1)] = [\alpha\ MDL_1 (A_2/A_1)]$ provided that $TLR_2 \geq [MDL_1 (A_2/A_1)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(MDL_1 (A_2/A_1)] < 0.2$
Threshold, T_2 – gal/h	$T_2 = [(TLR_1 - C_{MDL\ 1}) (A_2/A_1)] = [\beta\ MDL_1 (A_2/A_1)] \geq 0.1$ or $T_2 = 0.1$ when $[(TLR_2 - C_{MDL\ 1}) (A_2/A_1)] < 0.1$
P_D – %	95%
P_{FA} - %	$\leq 5\%$
*The target leak rate TLR_2 is computed for the tank to be tested from TLR_1. **Define MDL_1 and $C_{MDL\ 1} = MDL_1/2$ for A_1; S for A_1 ; A_1; α and β is a constant multiplier on MDL_1.	

Operation of the Evaluated System

Versions 2.0, 2.1, 2.2 Mass Based Systems (with scaling and averaging included)	
	Test Threshold *** Set P_D = 95% against a Target Leak Rate $TLR_1 \geq MDL_1$ and insure the $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	$TLR_2 = [(TLR_1/n^{0.5}) (A_2/A_1)] = [(\alpha\ MDL_1 /n^{0.5}) (A_2/A_1)]$ provided that $TLR_2 \geq [(MDL_1/n^{0.5}) (A_2/A_1)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(MDL_1/n^{0.5}) (A_2/A_1)] < 0.2$ with $1 \leq n \leq 24$
Threshold, T_2 – gal/h	$T_2 = [((TLR_1 - C_{MDL})/n^{0.5}) (A_2/A_1)] = [(\beta\ MDL_1/n^{0.5}) (A_2/A_1)] \geq 0.1$ $T_2 = 0.1$when $[(TLR_2 - C_{MDL})/n^{0.5}) (A_2/A_1)] < 0.1$ with $1 \leq n \leq 24$
P_D – %	95%
P_{FA} - %	$\leq 5\%$
*The target leak rate TLR_2 is computed for the tank to be tested from TLR_1. **Define MDL_1 and $C_{MDL\ 1} = MDL_1/2$ for A_1; S for A_1; and A_1; $1 \leq n \leq 12$; α and β is a constant multiplier on MDL_1.	

LRDP-24 Versions 2.0, 2.1, 2.2	
	Test Threshold *'** Set P_D = 95% against a Target Leak Rate $TLR_1 \geq MDL_1$ and insure the $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	$TLR_2 = [(TLR_1/n^{0.5}) (A_2/21{,}253)] = [\alpha\ 0.932\ (A_2/A_1)]$ provided that $TLR_2 \geq [0.932\ (A_2/21{,}253)] \geq 0.2$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(0.932\ (A_2/21{,}253] < 0.2$
Threshold, T_2 – gal/h	$T_2 = [(TLR_1 - 0.466)\ (A_2/21{,}253] = [(\beta\ 0.932/n^{0.5})\ (A_2/A_1)] \geq 0.1$ or $T_2 = 0.1$ when $[(TLR_2 - 0.466)\ (A_2/21{,}253)] < 0.1$
P_D – %	95%
P_{FA} - %	≤5%

*The following values of TLR_1 were selected: (1) 0.932 gal/h; (2) 1.15 gal/h; (3) 1.86 gal/h; (4) 3.5 gal/h
**MDL_1 = 0.932 gal/h; $C_{MDL\ 1}$ = 0.466; S = 0.272 gal/h; and A_1 = 21,253 ft^2; α and β is a constant multiplier on MDL_1, where α = 1.0, 1.24, 2.0, and 3.76, and β = 0.50, 0.73, 1.50, 3.26, respectively for the four TLR_1's specified above.

LRDP-24-n Versions 2.0, 2.1, 2.2	
	Test Threshold *'** Set P_D = 95% against a Target Leak Rate $TLR_1 \geq MDL_1$ and insure the $P_{FA} \leq 5\%$
Target Leak Rate, TLR_2 – gal/h	$TLR_2 = [(TLR_1/n^{0.5}) (A_2/21{,}253)] = [(\alpha\ 0.932/n^{0.5}) (A_2/A_1)]$ provided that $TLR_2 \geq [(0.932/n^{0.5}) (A_2/21{,}253)]$ and $TLR_2 \geq 0.2$ or $TLR_2 = 0.2$ when $[(0.932/n^{0.5}) (A_2/21{,}253)] < 0.2$ with $1 \leq n \leq 24$
Threshold, T_2 – gal/h	$T_2 = [((TLR_1 - 0.466)/n^{0.5}) (A_2/21{,}253)] = [(\beta\ 0.932/n^{0.5}) (A_2/A_1)] \geq 0.1$ $T_2 = 0.1$when $[TLR_2 - (0.466/n^{0.5}) (A_2/21{,}253)] < 0.1$ with $1 \leq n \leq 24$
P_D – %	95%
P_{FA} - %	≤ 5%

*The following values of TLR_1 were selected: (1) 0.932 gal/h; (2) 1.15 gal/h; (3) 1.86 gal/h; (4) 3.5 gal/h
**MDL_1 = 0.932 gal/h; $C_{MDL\ 1}$ = 0.466; S = 0.272 gal/h; and A_1 = 21,253 ft^2; $1 \leq n \leq 12$; α 2 and β is a constant multiplier on MDL_1, where α = 1.0, 1.24, 2.0, and 3.76, and β = 0.50, 0.73, 1.50, 3.26, respectively for the four TLR_1's specified above.

Appendix F

Listings for the LRDP-24 for ASTs

Prepared for Submission to the National Work Group on Leak Detection Evaluations (NWGLDE)

Vista Research, Inc., and Naval Facilities Engineering Service Center

LRDP-24 (V2.0.1.15,V2.0.3.50)

BULK FIELD-CONSTRUCTED AUTOMATIC TANK GAUGE MONITORING AND TIGHTNESS TEST LEAK DETECTION METHOD FOR ASTS

Certification: Leak rate is proportional to product surface area (PSA).
For tanks with PSA of 21,253 ft², leak rate is 1.15 or 3.50 gph with $P_D = 95\%$ and $P_{FA} = 0.97\%$ or $P_{FA} < 0.001\%$, respectively. Choose one to determine the scaled leak rate and scaled leak threshold for the tank being monitored.
For other tank sizes, scaled leak rate equals [(PSA in ft² ÷ 21,253 ft²) x (leak rate in gph)].
Example: For a tank with PSA = 10,000 ft², leak rate = 1.15 gph; scaled leak rate = [(10,000 ft² ÷ 21,253 ft²) x 1.15 gph] = 0.54 gph.
Calculated minimum detectable leak rate is 0.932 gph with $P_D = 95\%$ and $P_{FA} = 5\%$.
Leak rate may not be scaled below 0.2 gph.

Leak Threshold: Leak threshold is proportional to product surface area (PSA).
For tanks with PSA of 21,253 ft² and leak rate of 1.15 or 3.50 gph, leak threshold is 0.68 or 3.03 gph, respectively.
For other tank sizes, scaled leak threshold equals [(PSA in ft² ÷ 21,253 ft²) x (leak rate in gph - 0.466 gph)].
Example: For a tank with PSA = 10,000 ft², leak rate = 1.15 gph; scaled leak threshold = [(10,000 ft² ÷ 21,253 ft²) x (1.15 gph - 0.466 gph)] = 0.32 gph.
A tank system should not be declared tight if the test result indicates a loss or gain that equals or exceeds the calculated leak threshold.

Applicability: Gasoline, diesel, aviation fuel.
Other liquids may be tested after consultation with the manufacturer.

Tank Capacity: Use limited to single field-constructed vertical tanks larger than 50,000 gallons.
Maximum product surface area (PSA) is 53,133 ft² (approximately 260.1 ft. diameter).
Performance not sensitive to product level.

Waiting Time: Minimum of 0 hours after delivery or dispensing.

Test Period: Minimum of 20 hours.
There must be no dispensing or delivery during test.

Temperature: Measurement not required by this system.

Water Sensor: None. Water leaks are measured as increase in mass inside tank.

Calibration: Differential pressure sensor must be checked regularly in accordance with manufacturer's instructions.

Comments: Tests only portion of tank containing product.
As product level is lowered, leak rate in a leaking tank decreases (due to lower head pressure). Consistent testing at low levels could allow a leak to remain undetected.
Evaluated in a nominal 6,470,000 gallon, vertical underground tank with product surface area (PSA) of 21,253 ft².
Evaluated as a stand-alone system.
Performance of the system can be improved by combining results of 2 or more tests. If this option is used, it is important to determine the number of tests, their timing and the number of passing results necessary to confirm a tank is tight. The LRDP-24-n (V2.0, V2.1, V2.2) combines the results of n tests, where n ≤ 24 and is one evaluated option to improve the performance of this system.

Vista Research, Inc.
755 N. Mary Avenue
Sunnyvale View, CA 94085
Tel: (408) 830-3300

Evaluator: Ken Wilcox Associates
Tel: (816) 443-2494
Date of Evaluation: 06/19/02

Vista Research, Inc., and Naval Facilities Engineering Service Center

LRDP-24 (V2.1)

BULK FIELD-CONSTRUCTED AUTOMATIC TANK GAUGE MONITORING AND TIGHTNESS TEST LEAK DETECTION METHOD FOR ASTS

Certification:	Leak rate is proportional to product surface area (PSA). For tanks with PSA of 21,253 ft², leak rate is 1.86 gph with P_D = 95% and P_{FA} = 0.0016%. For other tank sizes, scaled leak rate equals [(PSA in ft² ÷ 21,253 ft²) x (leak rate in gph)]. Example: For a tank with PSA = 10,000 ft², leak rate = 1.86 gph; scaled leak rate = [(10,000 ft² ÷ 21,253 ft²) x 1.86 gph] = 0.88 gph. Calculated minimum detectable leak rate is 0.932 gph with P_D = 95% and P_{FA} = 5%. **Leak rate may not be scaled below 0.2 gph.**
Leak Threshold:	Leak threshold is proportional to product surface area (PSA). For tanks with PSA of 21,253 ft² and leak rate of 1.86 gph, leak threshold is 1.40 gph. For other tank sizes, scaled leak threshold equals [(PSA in ft² ÷ 21,253 ft²) x (leak rate in gph - 0.466 gph)]. Example: For a tank with PSA = 10,000 ft², leak rate = 1.15 gph; scaled leak threshold = [(10,000 ft² ÷ 21,253 ft²) x (1.86 gph - 0.466 gph)] = 0.66 gph. A tank system should not be declared tight if the test result indicates a loss or gain that equals or exceeds the calculated leak threshold.
Applicability:	Gasoline, diesel, aviation fuel. Other liquids may be tested after consultation with the manufacturer.
Tank Capacity:	Use limited to single field-constructed vertical tanks larger than 50,000 gallons. Maximum product surface area (PSA) is 53,133 ft² (approximately 260.1 ft. diameter). Performance not sensitive to product level.
Waiting Time:	Minimum of 0 hours after delivery or dispensing.
Test Period:	Minimum of 20 hours. There must be no dispensing or delivery during test.
Temperature:	Measurement not required by this system.
Water Sensor:	None. Water leaks are measured as increase in mass inside tank.
Calibration:	Differential pressure sensor must be checked regularly in accordance with manufacturer's instructions.
Comments:	Tests only portion of tank containing product. As product level is lowered, leak rate in a leaking tank decreases (due to lower head pressure). Consistent testing at low levels could allow a leak to remain undetected. Evaluated in a nominal 6,470,000 gallon, vertical underground tank with product surface area (PSA) of 21,253 ft². Evaluated as a stand-alone system. Performance of the system can be improved by combining results of 2 or more tests. If this option is used, it is important to determine the number of tests, their timing and the number of passing results necessary to confirm a tank is tight. The LRDP-24-n (V2.0, V2.1, V2.2) combines the results of n tests, where n ≤ 24 and is one evaluated option to improve the performance of this system.

Vista Research, Inc.
755 N. Mary Avenue
Sunnyvale View, CA 94085
Tel: (408) 830-3300

Evaluator: Ken Wilcox Associates
Tel: (816) 443-2494
Date of Evaluation: 06/19/02

Appendix G

Specification Sheet for the LRDP for ASTs

LRDP for ASTs

Low-Range Differential Pressure System

Product Data Sheet And System Specification

Dimensions

Diameter of Base Sensor Cylinder	7 13/16 in. (19.9 cm)
Height of Base Sensor Cylinder	16.0 in. (45.7 cm)
Diameter of reference tube	3 ½ in. (8.9 cm)
Height of constant diameter reference tube	0 to 50 ft (15.2 m)
Height of shaped reference tube	0-12 ft (3.7 m); 0-50 ft (15.2 m)
Embedded controller (2 connected units) or PLC	12 in. x 12 in. x 8 in. (ea. unit) (30.5 cm x 45.7 cm x 10.2 cm)

Weight

Base Sensor Cylinder (Empty)	35 lbs (16 kg)
Constant diameter reference tube, including conduit	5 lbs/ft (2.3 kg)
Shaped reference tube, including conduit	5 lbs/ft (2.3 kg)
Embedded controller (2 units)	60 lbs (27.3 kg)

Detectable Leak Rate

(Probability of detection of 95% with a probability of false alarm of 5%)	*For tank diameters less than 76.2 ft*	0.20 gal/h
	For tank diameters (D in ft) up to 260.1 ft	$(3.14*(D*0.5)^2/21{,}253)*0.93$ gal/h
	For tank diameters $D = [5{,}806.4*(n)^{0.5}]^{0.5}$ *(LRDP-24-n*	0.20 gal/h (average of $1 \leq n \leq 24$ tests)
(Probability of detection of 95% with a probability of false alarm of 1%)	*For tank diameters less than 68.6 ft*	0.20 gal/h
	For tank diameters (D in ft) up to 260.1 ft	$(3.14*(D*0.5)^2/21{,}253)*1.15$ gal/h
	For tank diameters $D = [4{,}706.0*(n)^{0.5}]^{0.5}$ *(LRDP-24-n)*	0.20 gal/h (average of $1 \leq n \leq 24$ tests)
(Probability of detection of 95% with a probability of false alarm of 0.0016%)	*For tank diameters less than 76.2 ft*	0.20 gal/h
	For tank diameters (D in ft) up to 260.1 ft	$(3.14*(D*0.5)^2/21{,}253)*1.86$ gal/h
	For tank diameters $D = [2{,}905.2*(n)^{0.5}]^{0.5}$ *(LRDP-24-n)*	0.20 gal/h (average of $1 \leq n \leq 24$ tests)
(Probability of detection of 95% with a probability of false alarm of <0.001%)	*For tank diameters (D in ft) up to 260.1 ft*	$(3.14*(D*0.5)^2/21{,}253)*(2.0-0.466)$ gal/h
	For tank diameters (D in ft) up to 260.1 ft	$(3.14*(D*0.5)^2/21{,}253)*(3.0-0.466)$ gal/h

Power

In-tank sensor unit, embedded controller, interface computer	*Single-phase 120 VAC 60 Hz*

Temperature

Operating	-20° to 100° F (-29° to 38° C)

User Interface

System monitor	*Vista GUI software* *Windows 95 or FAS software*